# Real-Time Particle Size Tracking in Individual Hydrocyclones: New Field Results

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**ABSTRACT**

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

Two novel and robust technologies have been developed to address this challenge of unwanted coarse material in the individual hydrocyclone overflow streams that jointly become the flotation feed stream. This coarse material creates adverse effects in the flotation process and, sometimes, further downstream in the tailings thickening process. These technologies were developed and tested at a large North American copper concentrator where they continue to operate commercially for several years. Data from these installations has been previously presented.

This paper presents new data from two new installations in large South American copper concentrators. One of the systems is non-invasive and detects very coarse material 6 mm or greater in size. This system is in full commercial operation on all hydrocyclones in the primary classification area in one of the concentrators where its alarm capability has helped avoid costly events in rougher flotation due to coarse material accumulation.

The other system uses a wetted sensor and measures and tracks a key parameter of the slurry, such as %+150 um. This is accomplished without the need for slurry sampling and associated sample transfer piping circuits that are prone to plugging, thus avoiding high maintenance requirements. This system is in the final stages of a commercial trial on a complete hydrocyclone battery in the other concentrator.

Plant data for both systems will be presented that demonstrate that very high availability is achieved with very low maintenance. The %+150um tracking system has enabled improved process control by helping maintain throughput and ball mill power draw target while reducing grind size.

**Keywords:** particle size, hydrocyclone, grind circuit, instrumentation, optimization

## 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 100um to 200um 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 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. For each system, a specific problem is identified, and plant data is presented showing how the problem can be addressed using the new technology. In this paper “pebbles” are particles 6mm – 12mm and larger in diameter.

## OVERSIZE MONITORING SYSTEM (OSM)

### Introduction – OSM

The CYCLONEtrac OSM system offers operators the ability to detect performance issues for individual hydrocyclones in a battery in real-time, enabling them to take timely corrective action, thus minimizing the downstream effects on flotation. Additionally, the system provides the individual hydrocyclone isolation state. These features are provided from sensors mounted on the outside of the overflow pipes. Therefore, the system is very reliable and requires little maintenance.

Over several years of commercial operation in a large North American copper concentrator, the CYCLONEtrac 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.

On June 2, 2015, a complete CYCLONEtrac OSM system was installed and commissioned at Minera Centinela in Chile after a successful commercial trial on one hydrocyclone battery. The performance of the system during the trial and after the whole plant install will be discussed in this paper.

### System Description – OSM

One of CiDRA's core competencies is the measurement of acoustic information through the wall of a pipe (Gysling et al, 2005). 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 have a significant probability of striking the inside of a hydrocyclone overflow pipe as they pass through it. 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. For the OSM system a proprietary strain sensor is tightened mechanically onto the outside of individual hydrocyclone overflow pipes. The particle-induced strain, i.e. 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 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.

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.

## Plant Data – OSM

### *Trial site and installation and commissioning overview*

The second CYCLONEtrac OSM system was installed on a trial basis on a single hydrocyclone battery at Minera Centinela in northern Chile with a capacity of 97,000 t/d, which they are in the process of expanding to 105,000 t/d. This concentrator has one SAG mill and two ball mills, each feeding 2 hydrocyclone batteries for a total of 4 batteries. The consolidated overflow of the hydrocyclone batteries feeds one tank, which in turn feed two rougher flotation rows. Each of the 4 hydrocyclone batteries has 12 cyclones. Battery 3 and its 12 cyclones were instrumented with OSM in May, 2014. The system was commissioned, and the trial period formally began on June 23, 2014.

It was during the commissioning period, prior to the trial start, that a severe roping event affected battery 3, resulting in the rougher flotation feed tank overflowing, with the end consequence of a complete stoppage of one of the rougher flotation lines for ~6 hours. See Figure 1.


**Figure 1** Timeline of the May 27th severe roping event

This severe roping event was confirmed after evaluating PI data from the plant, in which one can observe an increase in mill power at around 8:10 AM, consistent with the start time of the roping events on cyclones 5 and 3. This increase in mill power is also consistent with the ball mill emptying due to a large number of solids reporting to the overflow vs. the underflow. See Figure 2.

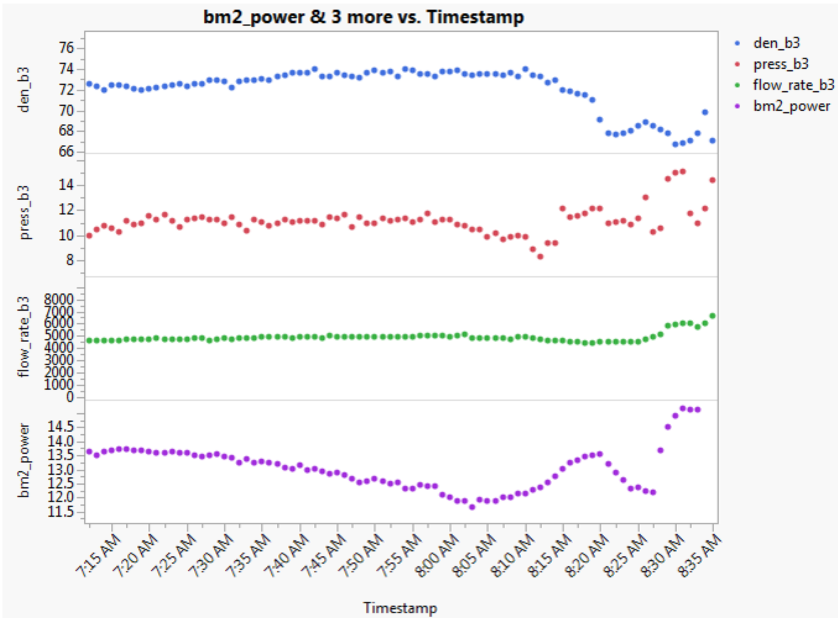


**Figure 2** PI data of the May 27th severe roping eve**nt**

## *Commercial Evaluation Period*

The CYCLONEtrac OSM system was commissioned and the commercial evaluation period formally started on June 23, 2014 and lasted for 3 months. During these 3 months several significant roping events were detected and major consequences avoided due to the CYCLONEtrac OSM system. Since the beginning of the commercial evaluation, no unscheduled rougher line shutdowns due to coarse material have occurred.

The first month is characterized by a slow operator response time to roping events due to the operators getting familiar with the system and, more importantly, verifying the information displayed by the system at the batteries. Through this month the operating procedure when the system alarmed a roping event was to notify the field operator and to visually confirm the roping event in the affected cyclones. Once visual confirmation was obtained, the control room operator shut down the offending cyclone.

The second month finds the operators becoming more comfortable with the system with average response time decreasing to 6 minutes. The operators trust the information displayed by the system and visual confirmation of the roping event is no longer requested. In cases where the field operator and a roping event coincide at battery 3, the information provided by the system is confirmed. Figure 3 shows a typical roping event and the operator responding by closing the valve of the offending cyclone.

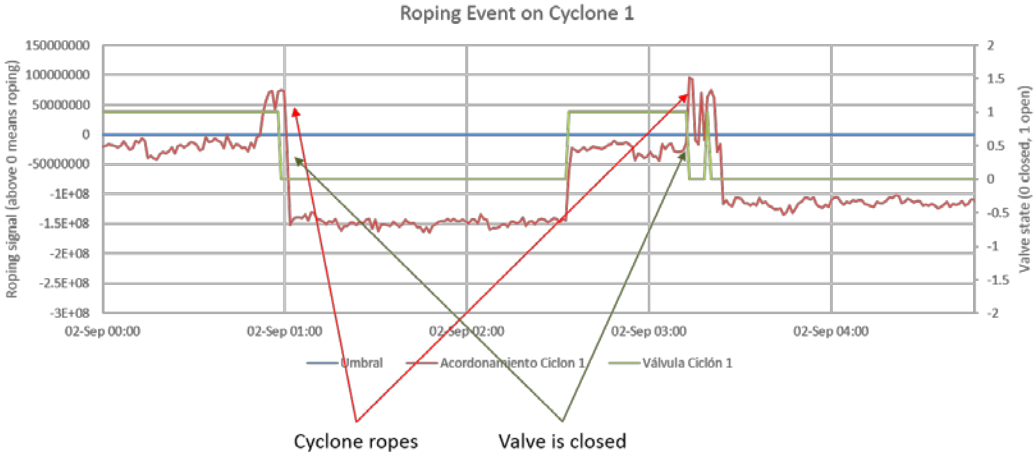


**Figure 3** Typical operator response to roping event

The last month of the evaluation period is characterized by the operators completely trusting the system, confident in its ability to accurately indicate roping events, and depending on the system to make operating decisions, even during emergency situations. One such emergency situation occurred on September 12th when 7 of the 12 cyclones started roping. Unable to control the situation, the decision was made to shut down the cyclone feed pump in order to avoid an overspill of the rougher flotation feed tank. The complete sequence can be observed in Figure 4.

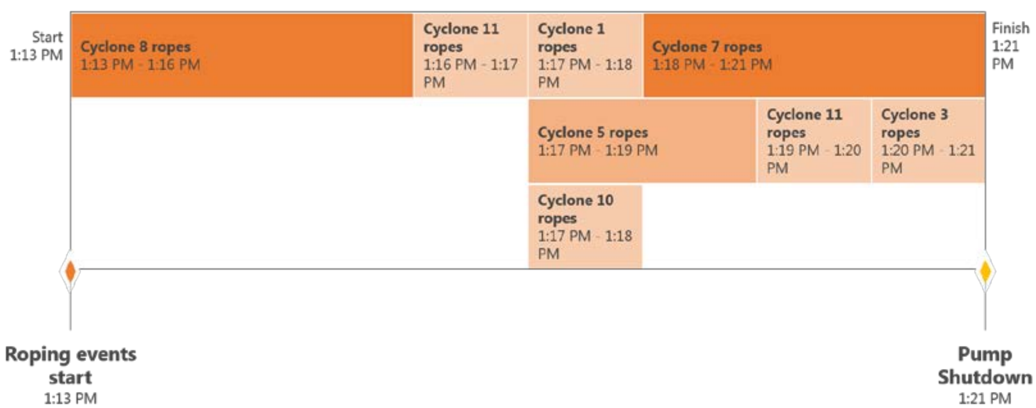


**Figure 4** Timeline of the September 12th severe roping event

At the end of the trial period, the operators trust and depend on the system completely. Many severe roping events have been detected by the system and acted upon by the operators, and not a single unscheduled shutdown due to coarse material has taken place. Operator response time averages 1 minute and 40 seconds.

After the end of the commercial evaluation period on September 23, 2014, Centinela conducted an internal review and, after several weeks, decided to instrument the remaining 3 batteries with CYCLONEtrac OSM, for a total of 48 sensors.

## Full system installation

The full CYCLONEtrac OSM system was successfully installed and commissioned on the other 3 batteries on June 2, 2015. All remaining cyclones were instrumented with CYCLONEtrac OSM in

1.5 calendar days, broken up into 30 minutes of installation time for each cyclone and 1 hour of system testing per battery. This extremely fast installation was due to the non-invasive nature of the system, coupled with the completion of the wiring, cable routing, and panel mounting before CiDRA arrived on-site.

The complete system, 4 batteries and 48 cyclones, has been working well at Centinela since the commissioning date, and multiple roping events have since been detected. To date, the information provided by the system remains local; however, the work necessary to integrate the signals into the DCS is already underway.

### Trial period lessons learned

CYCLONEtrac OSM's second installation worldwide taught CiDRA many valuable lessons. Due to the nature of the system and the relatively remote location of the concentrator, remote access became a key asset for both CiDRA and the Client. Without remote access to the CYCLONEtrac OSM computer in the control room, this system would have proven inviable.

The logistics of deploying this system proved complex due to many factors, such as immigration status of the CiDRA specialists, specialty equipment needed by the concentrator, personnel availability, etc. Several Force Majeure events during the installation and commissioning of the system further complicated the project. CiDRA has learned that delays intrinsic to the nature of the project are compounded by minor delays in support work, such as cable routing, panel mounting, electrical wiring, and Ethernet connection to control room. This work can and, ideally, should be completed before CiDRA specialist engineers arrive on-site. Case in point, the very short installation time required to install the system on the remaining 3 batteries.

### Conclusion – OSM

The CYCLONEtrac OSM is a valuable tool for operators, who use it to avoid major issues downstream in the process. Many other capabilities of the system remain unexplored as of now at the customer site, such as cyclone wear monitoring, fully automatic alarm control, and closed loop control with the grinding circuit. However, we are confident that as the customer uses the system many of these capabilities will be implemented. The close and open relationship between Centinela and CiDRA, built on trust and maintained by the willingness of everyone involved to bring this state-of-the-art system to Chile, was what made this second installation a success.

## PARTICLE SIZE TRACKING SYSTEM (PST)

### Problem Statement – Poorly Performing Cyclones

A typical grinding circuit uses a configuration of multiple cyclones operating in parallel in a battery, with single feed and discharge lines common to the entire battery. Since there has traditionally been no instrumentation on individual cyclones, this configuration makes it very difficult to identify cyclones that are performing poorly and to quantify this effect on the grind-classification process. This case study shows how a poorly performing cyclone (transient event) was identified using the CYCLONEtrac PST system and quantifies the effect on the grinding circuit performance.

## System Description – PST

The CYCLONEtrac PST system consists of a small probe that is inserted into the overflow pipe of individual cyclones to make contact with the flowing slurry. Particles in the slurry impact the probe and produce an acoustic signal that is correlated to the characteristic size of the particles, such as the percent above a certain size, e.g. % +150 um. The individual cyclone PST signals are then used in a control system to permit two key functions: 1) provide a real-time indication of the final product size that is used to adjust certain process parameters, e.g. battery feed density, to control in real-time the final product size to a desired set point; and 2) identify poorly performing cyclones and take corrective action, e.g. shut and reopen the cyclone to 'reset it', or shut the offending cyclone and replace it with another with lower operating hours. The following case study addresses the latter function.

## Plant Data – PST – Impact of a single cyclone on the ball mill circuit

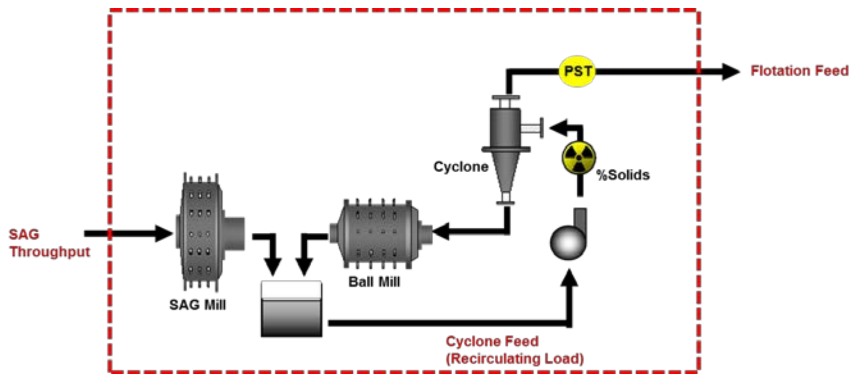


**Figure 5** SABC circuit flow chart

This case study is from a large copper concentrator with a SABC circuit. The SAG mill trommel screen underflow is gravity fed to two ball mills, each having an independent discharge sump. The ball mills are in closed circuit with a cluster of 14 Krebs Gmax 26-inch cyclones. Figure 5 shows the flow sheet of one of the two ball mill grinding lines.

The analysis and discussion is based on the following assumptions:

- Equal split of the SAG mill trommel screen underflow to each ball mill.
- If a cyclone is in a normal state (i.e. not blocked or roping) then it has equal overflow and performance to all other operational cyclones in normal state.
- Under steady state conditions, SAG throughput is equal to combined cyclone overflow.

### *CYCLONEtrac PST data*

Figure 6 shows the CYCLONEtrac PST measurement (% +100mesh) on cyclone 10 and the average PST measurement for all operational cyclones over a 1.5 hour time period. There are two distinct time periods (highlighted on the figure) where cyclone 10 is in an abnormal state, in which a significantly higher particle size product is being produced. The events are approximately ten and seven minutes in duration respectively.

A sample was cut from the overflow stream of cyclone 10 during the second event. The sample was difficult to obtain because the overflow pipe no longer had an air core and contained a large amount of oversized particles. The sample was wet sieved to get a value of 59% +100mesh However, Figure 6 shows that the PST signal does not increase to 59% because the PST system does not measure rocks and pebbles, which were included in the wet sieve sample.

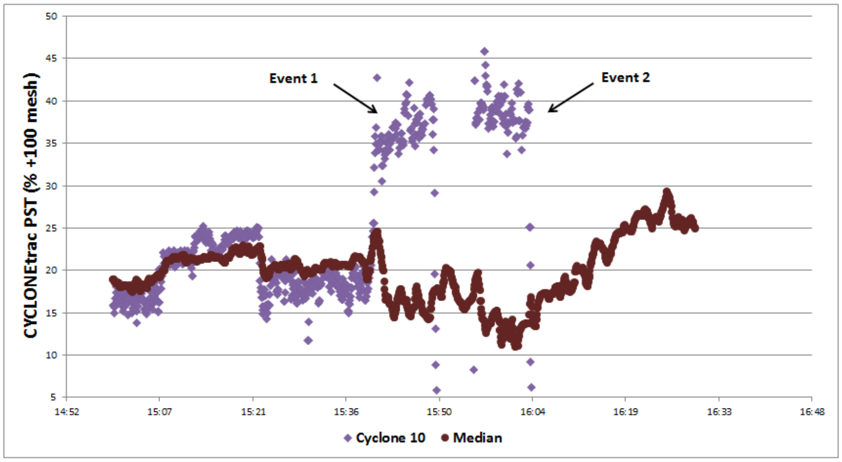


**Figure 6** CYCLONEtrac PST measurement (% +100mesh) on cyclone 10 and the average PST measurement for all operational cyclones over a 1.5 hour time period

### *Analysis and Discussion*

Figure 7 shows the ball mill power over the same time period. As indicated on the figure, the two consecutive cyclone events described above have a significant impact on the ball mill. The events effectively unload the ball mill, as indicated by the significant increase in power draw (6000kW to 6175kW). When the poorly operating cyclone is switched off between the two events, the ball mill load begins to increase (power draw decreases). However, when the cyclone is returned to service, the ball mill load decreases further as the cyclone is still in an abnormal state. Once cyclone 10 is turned off and remains off, the ball mill load approaches the initial conditions.

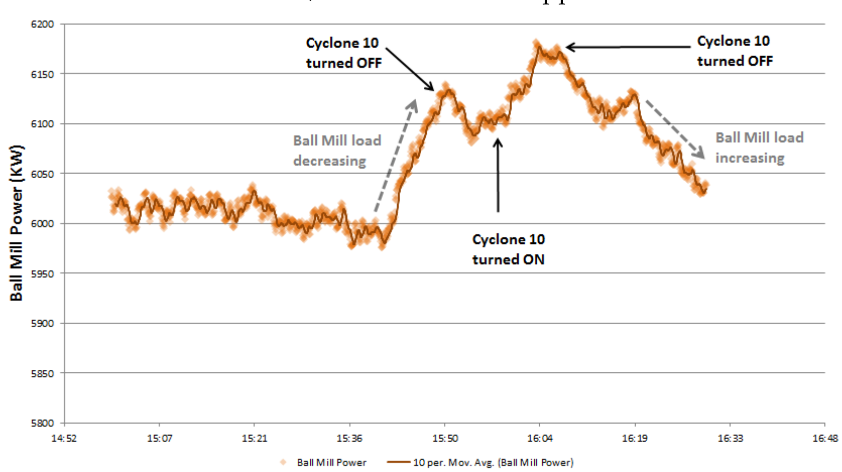


**Figure 7** Ball mill power over same 1.5 hour time period

Figure 8 shows the SAG throughput and ball mill distribution dart valves. There is an increase in fresh feed during the first half hour, and then the feed rate and dart valves remain constant during the two cyclone events. Without an increase/decrease in the ball mill recirculating load, the cyclone overflow stream should also be constant when the SAG feed rate is constant. During the two cyclone events the mass flow decreases significantly (Figure 9), indicating a decrease in the recirculating load in the ball mill circuit. An approximate integration of the mass flow curve during the two events gives the mass loss, which can be converted to an equivalent rate (t/h). The mass loss rate is in addition to the mass being produced under steady state conditions (approximately 120 to 200 t/h per cyclone).

- Event 1: 210 tons lost. Equivalent rate is 1260t/h.
- Event 2: 110 tons lost. Equivalent rate is 872 t/h.

CYCLONEtrac PST data (Figure 6) support that the mass loss is from cyclone 10 operating in an abnormal state. This is also supported by the observation of a lack of air core and predominantly full overflow pipe during the sampling. Interestingly, during the events the other operational cyclones start producing a finer product leading to a lower particle size, as indicated by the decrease in the PST median value (Figure 6). However, the PST measurement is not weighted by mass or volumetric flow, and therefore the consolidated overflow stream is likely to be significantly coarser given the high mass flow from cyclone 10. The finer product from the cyclones in normal state is likely due to the their lower feed rate as the hydraulic balance has been disrupted and mass is short circuiting to the overflow stream via cyclone 10. This highlights the importance of individual cyclone performance monitoring given the impact a single cyclone in an abnormal condition can have on the ball mill circuit and the downstream process.

This type of event is rather common and can have various causes, for example: a sudden change in volumetric flow to the battery caused by a change in pump speed and/or increasing or decreasing the number of operating cyclones; a sudden change in the mass flow rate and/or particle size in the individual cyclone feed caused by a flow disturbance in the battery distribution box; partial or complete blockage of the cyclone apex; or other causes that disturb the hydrodynamic stability of the cyclone.

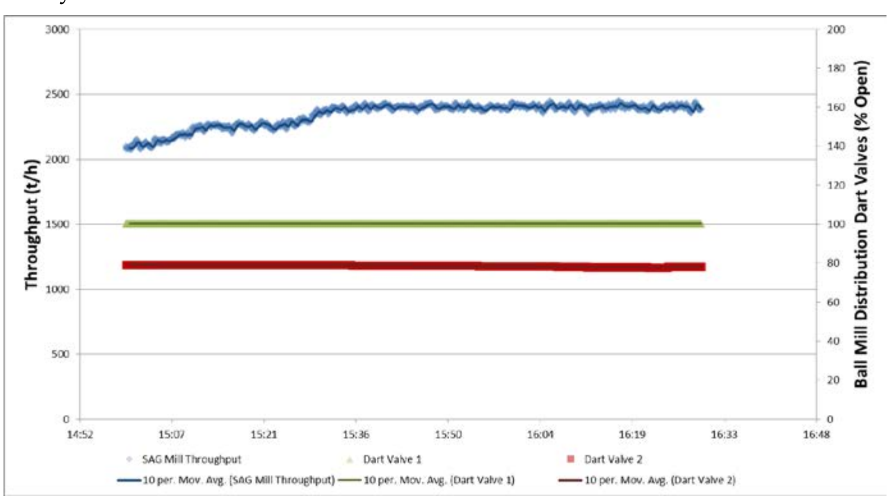


**Figure 8** SAG throughput and ball mill distribution dart valve status over same 1.5 hour time period

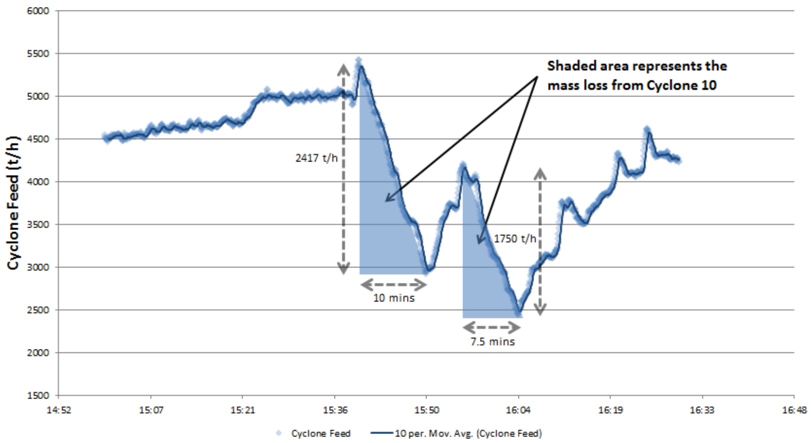


**Figure 9** Feed to cyclones in tons per hour over same 1.5 hour time period

## Conclusion – PST

It has been shown that the PST sistem can identify an individual cyclone that is performing poorly in a battery of many cyclones. A simple methodology has been demonstrated that cuantifies the significant mass loss caused by a poorly performing cyclone which will negatively affect the downstream flotation and tailings thickening processes.

## CONCLUSION – GENERAL

Using plant data, it has been shown that a non-invasive instrument for detecting rocks and pebbles in cyclone overflow streams can reliably detect a roping cyclone and, thus, enable operators to quickly shut the cyclone to avoid pebbles and rocks from arriving to the downstream rougher flotation and tailings processes. It was also shown that an invasive instrument for individual cyclone overflow streams can track in real-time the characteristic particle size of the slurry and, thus, provide a means for detecting oversize material that is smaller than rocks and pebbles but can also be problematic for downstream processes, such as rougher flotation, tailings transport and thickening. For the second instrument a methodology was shown that quantifies the amount of the unwanted oversize material discharged by the poorly performing cyclone. Both systems can be integrated into a control system to help optimize the grinding-classification circuit.

## ACKNOWLEDGEMENTS

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## REFERENCE

Gysling, D.L., Loose, D.H. & van der Spek, A.M. (2005) 'Clamp-on, sonar-based volumetric flow rate and gas volume fraction measurement for industrial applications', *Flomeko*, Jun. 6-9.