The value of real-time particle size tracking on individual cyclones

Dylan Cirulis[1]*, Christian O'Keefe[2], Juan F. Medina[3] and Robert J. Maron[4]

1. *CiDRA Minerals Processing, USA*
2. *CiDRA Minerals Processing, USA*
3. *CiDRA Minerals Processing, USA*
4. *CiDRA Minerals Processing, USA*

ABSTRACT

Since large pumps became available in the 1950's with enough capacity to create rotary motion required for cyclone classification, the cyclone has held a strong place in the minerals processing industry (Lynch, 2015). Cyclones are simple to use and have large turndown ratios making them the preferred choice for large closed grinding circuits, and will likely remain so for the near future. Despite their simplicity, cyclones are imperfect classifiers and have inefficiencies associated with fine and coarse material bypassing to the undesired stream. Furthermore, even though cyclones are normally arranged in a cluster or pack, and fed by a common distributor, individual performance can vary significantly. Cyclone performance can severely impact overall plant performance through grinding efficiency (unwanted fines in ball mill feed), throughput (shut down due to blockages) and mineral recovery (through unwanted coarse material in the feed for the downstream separation process).

This paper presents a novel and robust technology that has been developed with an industry partner to address the challenge of unwanted coarse material in cyclone overflow streams. The CYCLONEtrac particle size tracking (PST) system will be described in detail along with the calibration approach for which a rapid method for analyzing cyclone overflow samples was developed to minimize the errors involved. The system has sensors installed on individual cyclones, providing a particle size measurement, thus performance monitoring of individual cyclones. This compares to the traditional approach of measuring a sample stream of the consolidated overflow from a cyclone cluster. Plant data will be presented showing the value of individual measurement.

INTRODUCTION

In a minerals processing concentrator involving comminution and subsequent flotation, valuable mineral recovery is strongly linked to the particle size distribution of the flotation feed material.

The optimum particle size is determined by the liberation size and the plant tradeoff between recovery and throughput, and must be neither too fine nor too coarse. In general, reducing the amount of coarse material can significantly improve recovery of a plant. Unwanted coarse particle delivery is usually caused by poor control of the grinding process or deficiencies in hydrocyclone classification. Reducing the amount of undesired fines can significantly increase grade, increase throughput, and potentially increase recovery. This paper presents a solution to the challenge of maintaining the optimal particle size in flotation feed.

Through an industry partnership CiDRA developed a novel technology for the measurement of particle size in individual hydrocyclone overflow pipes. The system provides real-time overflow product size information that enables immediate corrective action by operators or various control room strategies. The solution has been commercially deployed and will be described in detail. Plant data is presented showing examples of how the data can be used to identify plant operating problems.

SYSTEM DESCRIPTION

The CYCLONEtrac PST system consists of sensor assemblies, junction box(es), 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 an acoustic impact signal is created. The impact response is processed by the on-board electronics in order to derive the particle size measurement for the slurry stream. The sensor assembly is powered by 24V and communicates to a junction box using MODbus protocol.

Figure 1 Left, CYCLONEtrac PST sensor. Right, CYCLONEtrac PST sensor installed on pipe

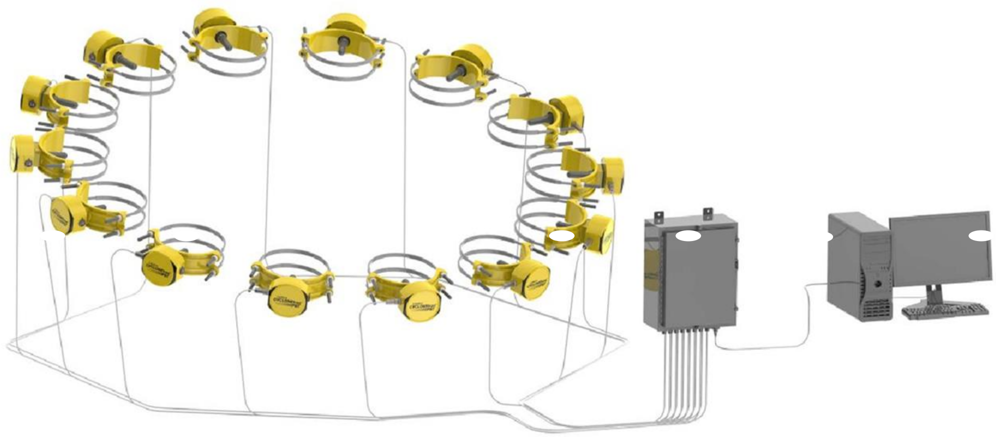

Figure 2 CYCLONEtrac PST system

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 Distributed Control System (DCS) via an OPC tunnel.

Existing overflow pipes are modified to accept a PST probe through a 2 inch (50mm) hole and the assembly is then 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 cluster has a number of available hydrocyclones that are not in use. This allows installation of the PST devices without grind circuit downtime since the cluster can continue operating.

Installation of a PST unit on a prepared overflow pipe can take as little as 10 minutes. The probe occupies a very small surface area compared to the cross sectional area of the pipe and the cylindrical shape creates minimal flow disturbance. Therefore there is no impact on cyclone performance due to overflow stream disturbances.

TECHNOLOGY COMPARISON

CYCLONEtrac PST differs from the traditional particle size measurement approach in a number of ways. Table 1 outlines some of the key differences between the available technologies used for particle size measurement in communication circuits. CYCLONEtrac PST was developed with an industry partner to bring a grind size measurement solution to comminution circuits. A demonstrated combination of high availability and fast update rate enable closed loop control of the comminution circuit product.

Table 1 Particle size measurement technology comparison

	CYCLONEtrac PST	Traditional consolidated cyclone overflow sampled systems using calibers, ultrasonics, laser diffraction	Laboratory sieving
Update rate	4 seconds	3-9 minutes	Typically 2 hours with 12-24 hours latency
Enables closed loop control	Yes	No	No
Full stream analysis	Yes	No	No
Requires sampler maintenance	No – sampler free	Yes	No
Availability	>98%	Typically low with exceptions	High
Number of particle sizes	1 currently (2 or more possible in future)	Multiple	Multiple
Performance monitoring of individual hydrocyclones	Yes	No	Possible but not typical

SYSTEM CALIBRATION

On-line cyclone overflow sizing methods, whether laser diffraction, ultrasonic, caliber or impact based, require calibration by correlating their signals to samples that are correspondingly analyzed with laboratory screens or to reference particles. According to Outotec literature, the PSI 300 which is a caliber based sizing device "a range of approximately 20 samples is required to get the most accurate calibration equation." The impact based CYCLONEtrac PST also requires calibration due to influences from cyclone type, operational conditions and sensor installation location. To ensure a good composite calibration that can be applied across all the cyclones in a cluster, calibration samples must be taken from each cyclone. Once such calibration takes place, it does not have to be performed again even if the probe is replaced. In addition, samples must be taken beyond the expected operating range of the cyclones. This avoids the measurement uncertainty that occurs when calibration models are used to extrapolate measurements beyond their calibrated range.

Uncertainties associated with calibration are dominated by two major factors: sampling and sieving. The relative contribution of the two factors on the total uncertainty can vary. The physical limitations frequently encountered in cyclone overflow sampling will cause the sampling uncertainty to dominate, particularly if a proper sieving and analysis procedure is chosen and implemented well. The goal is to reduce the confidence interval of the resulting calibration. Assuming that variances in the sampling are normally distributed, more samples will decrease the confidence interval of the calibration by the square root of the number of samples. The best sieving processes involves removing fines, drying the remaining sample and then dry sieving the sample in a stack. Unfortunately, this process is time, labor and equipment intensive, typically requiring 12 to 24 hours to complete, which includes the drying time. To process more samples with limited resources, a single size wet sieving procedure can be used. In a single size wet sieving procedure, a single screen is used to determine the percentage of material that is above a certain size. To reduce the time spent wet sieving and analyzing samples, so more samples can be processed, CiDRA developed dedicated equipment. To reduce the uncertainty of the wet slurry weight fraction analysis, CiDRA developed new techniques. The dedicated wet sieving equipment includes a custom shaker that uses large 12 inch diameter screens. Compared to commonly used 8 inch diameter screens, the larger screens provide 2.25 times the surface area. Portable wet sieving stations were developed to reduce time spent moving samples to a laboratory thus the wet sieving and analysis can take place near the sampling locations. A photo of the portable equipment including the custom shaker is show in Figure 3 Top view mobile wet sieving and wet slurry analysis stations. The custom shaker shown in middle

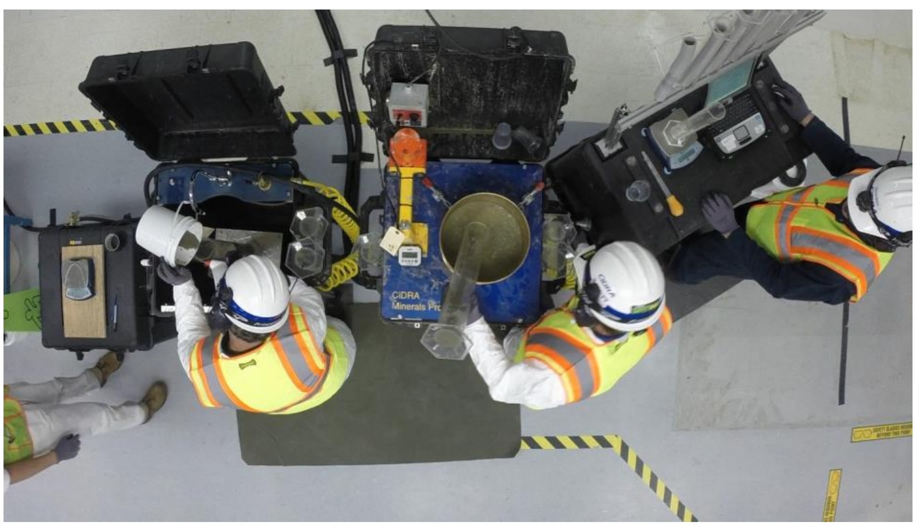

Figure 3 Top view mobile wet sieving and wet slurry analysis stations. The custom shaker shown in middle.

During a campaign in late 2015, approximately 15% of the samples were dry stack sieved. Within 1.5 minutes of the dry stack sieved samples, additional samples were taken from the same cyclones and these were single size wet sieved at 150micron, providing the percentage of material retained by the screen or %+150micron. One limitation of this comparison test is that overflow size distributions can change quickly during a 1.5 minute time period. The dry stacked results were compared to the wet sieved samples and the differences were calculated, Figure 4. From the eighteen samples a mean difference of 1.8 percentage points as well as a standard deviation of 2.3 percentage points were observed.

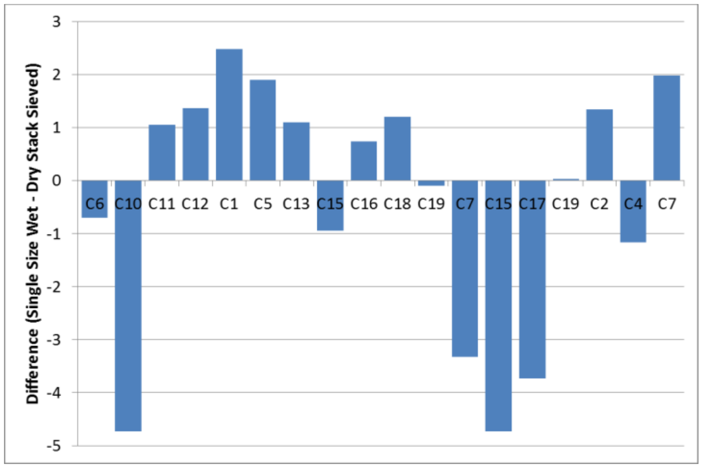

Figure 4 Difference **(**Dry stacked sieve laboratory results versus CiDRA's single size wet sieved results). The data nomenclature refers to the cyclone (example: C6 for cyclone six).

CYCLONEtrac PST probes were installed on 88 cyclones on the primary grind circuit of a large copper producer. Samples were taken from these cyclones of which 50% were used to generate the calibration coefficients for the %+150 micron measurement. The remaining 50% of the samples are used to validate the model as a way of ensuring it works for more than the calibration samples only. The calibrated outputs from the CYCLONEtrac PST probes were compared against the sieved results from all of the samples and a standard deviation of 4.5 percentage points in the %+150micron measurement was calculated. A graph of the results is shown in Figure 5 A comparison of the %+150 micron output from the CYCLONEtrac PST probes versus the %150 micron single point wet sieved samples (percentage of solids retained in a 150 micron screen), along with the sampling and sieving uncertainty derived from the dry stack sieved versus single size wet sieved paired tests.

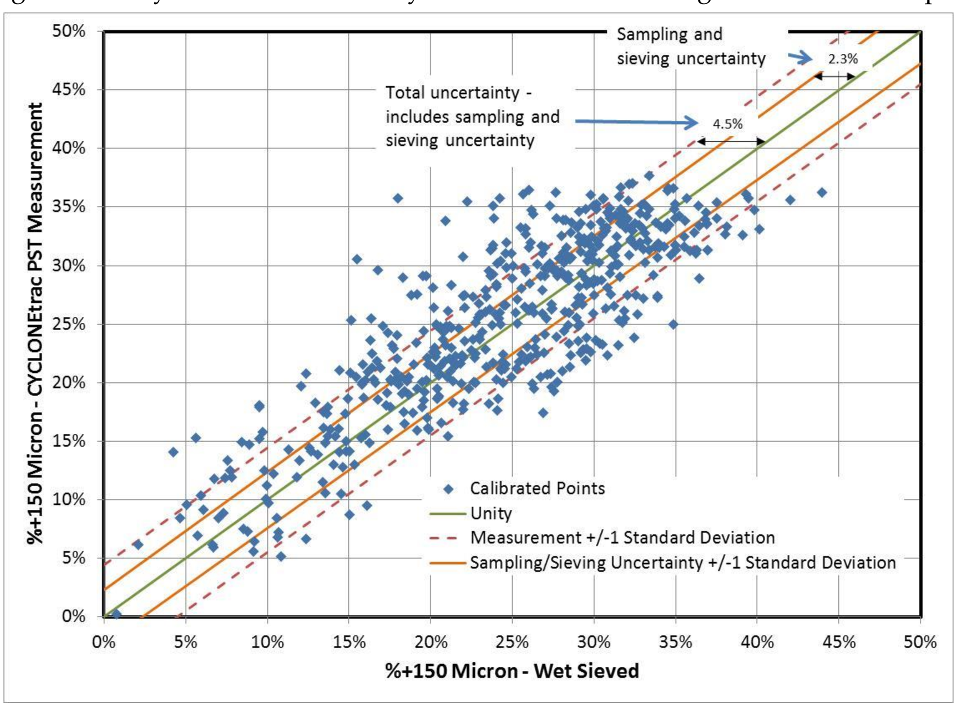

Figure 5 A comparison of the %+150 micron output from the CYCLONEtrac PST probes versus the %150 micron single point wet sieved samples (percentage of solids retained in a 150 micron screen)

CYCLONE PERFORMANCE

A typical grinding circuit uses a configuration of multiple cyclones operating in parallel in a cluster, with single feed and discharge lines common to the entire cluster. 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. Installation of the CYCLONEtrac PST system permits two key functions:

1) Provision of a real-time indication of the final product size that can be used to adjust certain process parameters, e.g. cyclone feed density and/or cyclone pressure, to control the final product size

2) Identification of poorly performing cyclones to allow corrective action e.g. cycle the cyclone off and on to 'reset it', or shut off offending cyclones and replace them with another with lower operating hours.

An in depth case study of item 1 has been reported previously (Cirulis *et al*, 2015). In this case the plant achieved significant improvements in throughput and particle size by control of a ball mill grinding and classification circuit. For item 2, previous analysis (Cirulis *et al*, 2015) has shown that one poorly performing cyclone can have a significant impact on the entire grinding and classification circuit. The following charts show more examples of poorly performing cyclones but rather than analyse the impacts on the grinding/classification circuit, the potential causes are discussed. The data is collected from an SABC circuit.

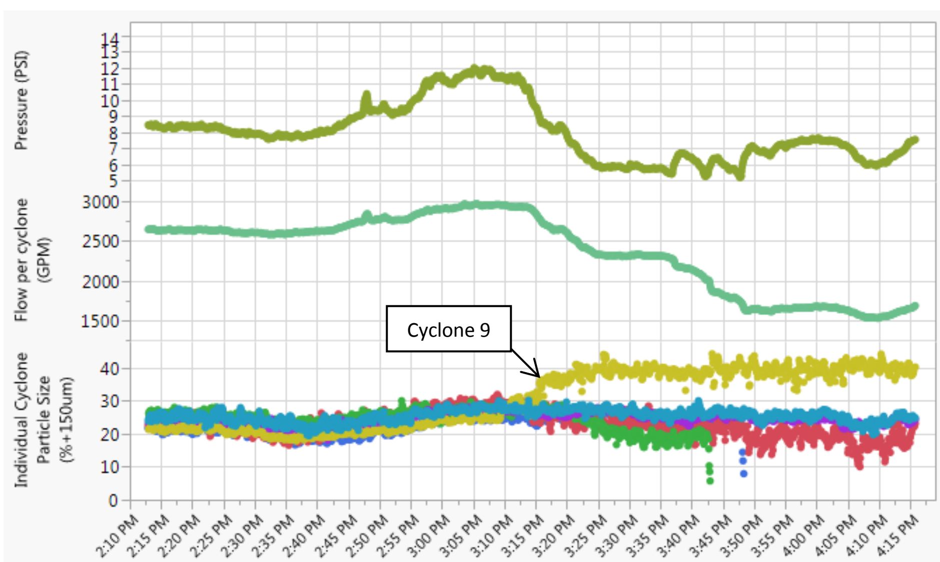

Figure 6 Grind circuit process data example 1

In Figure 6, cyclone 9 enters an out of class state at approximately 3:15PM following an increase in cyclone feed flow and cyclone pressure. Cyclone 9 continues to perform poorly, producing a particle size in excess of 40 % above 150micron for one hour. During this time period the recirculating load in the ball mill circuit, indicated by the feed flow, falls by over 1000 gallons per minute, attributed to the short circuiting out of cyclone 9. This material is discharged through the overflow of cyclone 9 resulting in an increase in the mass flow rate of flotation feed from that cyclone; therefore the consolidated cluster product is dominated by the coarse material from this one cyclone.

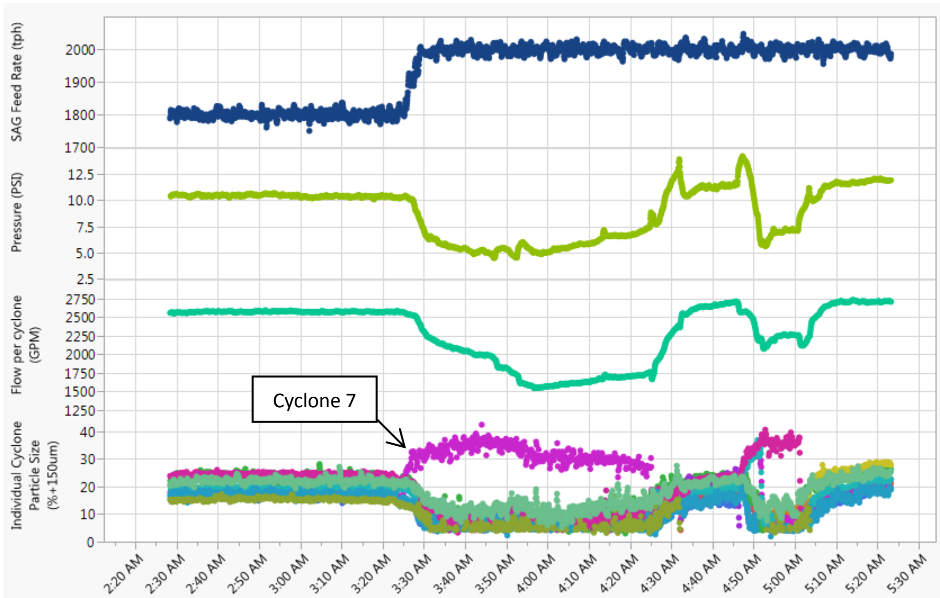

Figure 7 Grind circuit process data example 2

Figure 7 shows the circuit response to a 10 percent increase in SAG mill feed rate at 3:25AM. Almost instantly, cyclone 7 enters an out of class state and remains this way for 55 minutes before it is closed. Due to the short circuiting of the cyclone feed the load on the remaining cyclones is reduced, as inferred by the lower particle size product each cyclone produces. Once cyclone 7 is closed the cyclone feed flow and pressure recover and after a surge in cyclone pressure another 2 cyclones start to perform poorly for ten minutes after which they are closed.

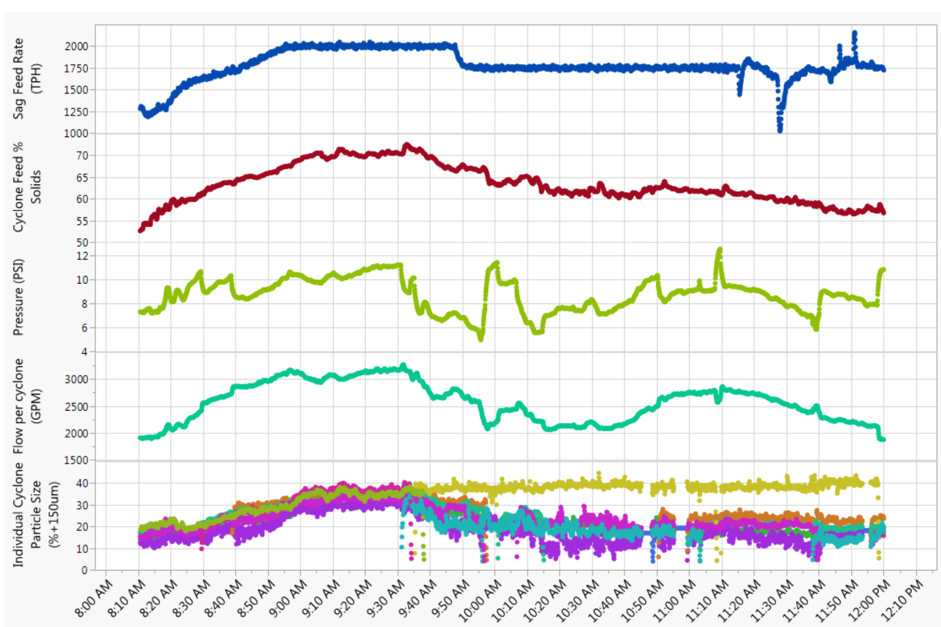

Figure 8 Grind circuit process data example 3

Figure 8 Grind circuit process data example 3 shows the circuit response to a 60 percent increase in SAG mill feed rate over a period of 45 minutes, starting at 8:10 AM. As the fresh feed rate increases the load in the ball mill circuit increases, indicated by the flow, pressure and feed percent solids increase. At 9:30 AM a small surge in the cyclone flow causes cyclone 7 to become out of class and continue producing a product size in excess of 40 percent above 150micron. Cyclone 7 remains in this state of operation for two and half hours, during which time the recirculating load falls as cyclone feed material short circuits to the cyclone overflow and to downstream flotation.

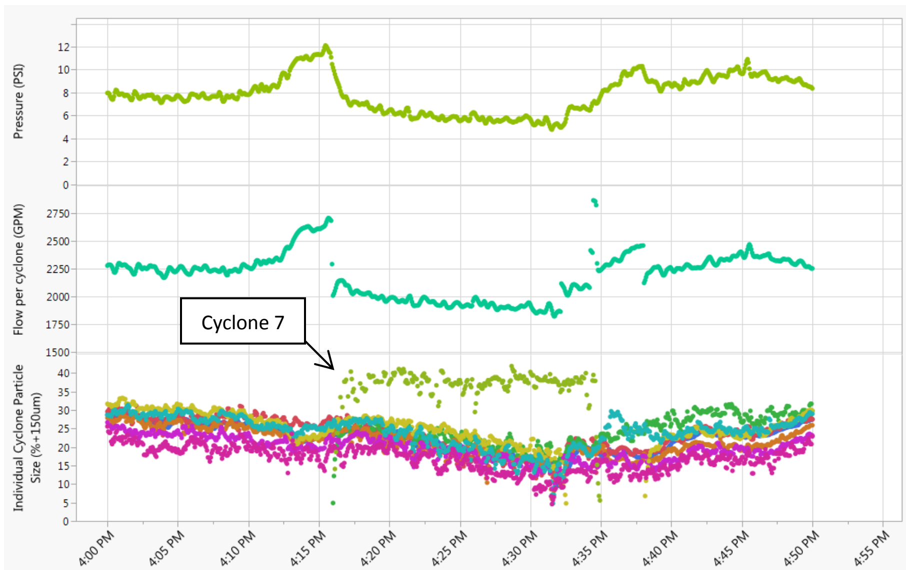

Figure 9 Grind circuit process data example 4

Cyclone open/close control is in a feedback loop with the cyclone pressure. Figure 9 Grind circuit process data example 4shows a time period where a cyclone is opened in response to a 2 psi increase in pressure. However, the cyclone that is opened is immediately in an out of class state suggesting that it likely had an apex blockage or another problem. While this cyclone remains open for 15 minutes it has a clear impact on the circuit in the form of a recirculating load (cyclone feed flow) reduction.

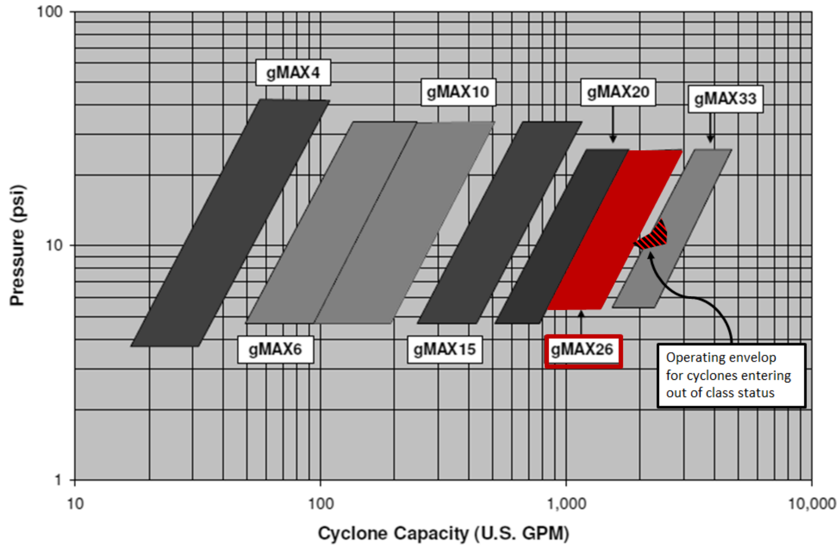

Figure 10 FLSmidth Krebs gMAX capacity curves (FLSmidth)

Cyclone capacity is defined by pressure, flow and the cyclone dimensions. Figure 10 FLSmidth Krebs gMAX capacity curves (FLSmidth) shows the capacity curves for FLSmidth Krebs gMAX cyclones. For the cases presented previously (all Krebs gMAX 26 cyclones) the flow and pressure at the time of the cyclones entering out of class status was plotted on Figure 10 FLSmidth Krebs gMAX capacity curves (FLSmidth) to create the striped shaded area. It is clear that in these cases the cyclone capacity is being exceeded and this may be the underlying cause. Interestingly, in many cases the number of cyclones open was not at the maximum suggesting that either the pressure control is not optimized or additional cyclones may not have been available due to maintenance or operational issues.

CYCLONEtrac PST data has revealed that the underlying issue may be that cyclone capacity needs to be increased if similar or high plant throughputs are to be run. Additionally the data has identified that there may be opportunities to optimize the cyclone control to maintain plant efficiency, in both the grinding circuit and downstream flotation.

CONCLUSIONS

CYCLONEtrac PST on individual cyclones has revealed data that would previously be virtually impossible to retrieve (i.e. through continuous sampling campaigns). This data can be used to:

1. Under automatic control, take corrective action to prevent efficiency losses (i.e. grinding efficiency and/or flotation recovery)
2. Under automatic control, optimize the grinding circuit control system to include real time individual cyclone data. Specifically, exploit opportunities to optimize pressure control, and to ensure cyclones operate within their specified flow and pressure ranges
3. Identify poorly operating cyclones for maintenance

Due to these benefits individual cyclone performance monitoring and control through the use of CYCLONEtrac PST should become standard instrumentation for cyclone classification in the minerals processing industry.

REFERENCES

Lynch, A., "Classifiers" in *Comminution Handbook,* Carlton, Australia: AusIMM, 2015, ch. *10*, pp.*150-152*.

Outotec Literature PSI 300 EN_150109.pdf, 2009

Cirulis, D., Dunford, S., Snyder, J., Bartsch, E., Rothman, P., Maron, R., Newton, D., O'Keefe, C., and Mercuri, J., 2015. Process optimization using real team tracking of coarse material in individual cyclone overflow streams in *Metplant 2015 Conference Proceedings*, Perth, Australia, 7-8 September

Cirulis, D., Zuzunaga, A., Jaque, A., Melo, F., Duarte, L. and Maron, R., 2015. Real-Time Particle Size Tracking in Individual Hydrocyclones: New Field Results in Proceedings of *Procemin 2015, 11th International Minerals Processing Conference,* Santiago, Chile, 21-23 October.

FLSmidth, *FLSmidth Krebs gMAX Capacity Curves- English Units*. Available: http://www.flsmidth.com/~/media/PDF%20Files/Liquid-Solid%20Separation/Hydrocyclones/gMAXCapacityCurveEnglishUnits.ashx