COMPARISON OF FLOTATION GRADE DYNAMICS ENABLED BY REAL-TIME MEASUREMENT

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ABSTRACT

The distinction between data suitable for process control and data subject to aliasing only becomes quantifiable with the availability of rapid real-time measurements. Expecting the dynamics of flotation to vary for different ore types, process flows and equipment types; a study was conducted to compare the dynamics of different flotation processes. The results shed light on the critical sampling intervals required for process control which in turn allows process stabilization and optimization. The technology used for the in-line measurements is based on diffuse reflective spectroscopy and has been introduced into the mineral processing industry over the past ten years. It has been widely implemented in the sulphide flotation industry in South Africa for the real-time measurement of grade.

BACKGROUND AND OBJECTIVE

A study was conducted by Du Plessis and Keet (2010) to quantify the minimum sample frequency required for grade and/or impurity control. The study was based on chromite data collected at 15 second intervals from the concentrate line of a flash float cell in the Platinum industry. The data captured the natural process variation of the entrained chromite through water recovery due to changes in feed parameters and flotation performance. It was found that the minimum rate of sampling required from the studied flash float concentrate was 2 minutes. This sampling interval time accounted for 90% of the variance in the process data. It was further found that a sampling interval time of longer than 4 minutes produced data with no significant correlation to reality.

The dynamics of the flotation process has been misjudged in the past but can be quantified with the availability of real-time grade measurement based on diffuse reflective spectroscopy.

The objective of the study was to compare the dynamics of different sulphide flotation processes through the comparison of maximum sampling intervals times required to combat aliasing.

All data were collected from single stream analyzers that are currently installed at mineral concentrators. The technology used is based on diffuse reflective spectroscopy.

CASE STUDIES INVESTIGATED

Building on the previous study, data was collected from the following applications:

- Case study 1: Platinum Group Metals (PGMs) and chromite grade from the final cleaner flotation stream at a Platinum concentrator in South Africa
- Case study 2:
- Feed and final concentrate grades of copper sulphide and copper oxide (acid soluble copper) from a copper concentrator in Zambia
- Case study 3: Chromite grade and two fractions of particles sizes from the flotation feed stream at a platinum concentrator in South Africa

For each of the case studies, Fourier transforms were used to quantify the sampling interval at which 90% of the signal variance is accounted for.

The Nyquist-Shannon sampling theorem states that a minimum sampling rate of more than twice the highest frequency component within a signal is required to avoid temporal aliasing distortion (also described as the wagon-wheel effect).

Although the Nyquist-Shannon theorem requires a sampling time of less than half the fastest time constant present in a system, closed-loop *automatic control* of such dynamics requires an even shorter sampling time. Franklin and Powell (1990) explained that the degradation due to discrete sampling is significant for sampling times longer than 10 times the fastest dynamic. This means that a multi-stream grade analyser with a sampling time of 15 minutes can be effectively applied for control only where significant process grades changes occur with time constants slower than several hours.

Case study 1: PGMs and chromite grade from final cleaner flotation stream at a Platinum Concentrator in South Africa

The study referred to previously was based on a flash float cell in the Platinum industry. The process dynamics between a flash float cell and final re-cleaner cell are expected to be different as the flash float represents main stream flotation and the final re-cleaner represents cleaner flotation.

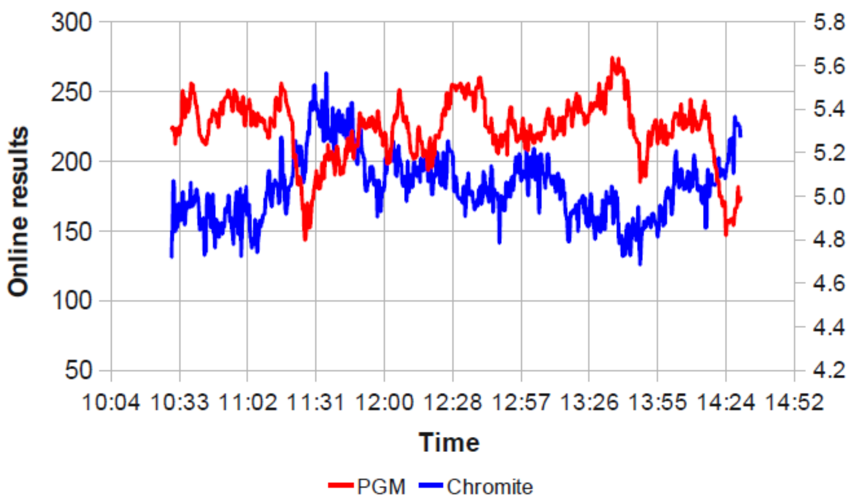

Figure 1 - SCADA online results for PGMs and chromite

Figure 1 illustrates the typical trends available for the PGM and chromite on the SCADA at increments of 15 seconds.

The Fourier transform of the data and variance accounted for from zero up to a certain frequency is shown as a function of inverse frequency (cycle time) in figure 2 for the PGMs and in figure 3 for the chromite. A darkened rectangle shows the high frequency components that only accounts for 10% of the variance and will therefore have a relatively small effect if not measured frequently enough.

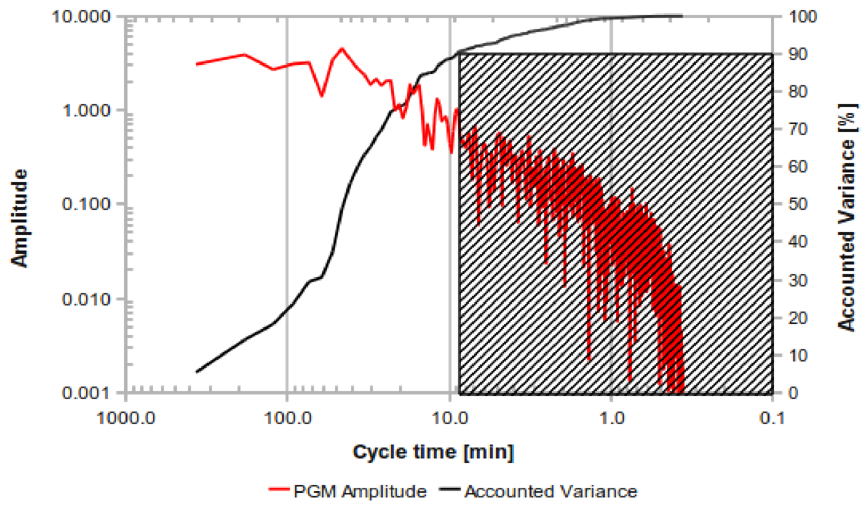

Figure 2 – Fourier transform and accounted variance for PGMs

The interval where 90% of the variance is captured for the PGMs equates to 9 minutes, resulting in a minimum sampling interval time of 4.5 minutes for the 4 hour period investigated. Changes in PGM grade with cycle times slower than 9 minutes account for 90% of variance. To capture these most important dynamics an absolute maximum sampling interval time of less than 4.5 minutes is required. If longer sampling interval times are used, significant temporal aliasing distortion will result.

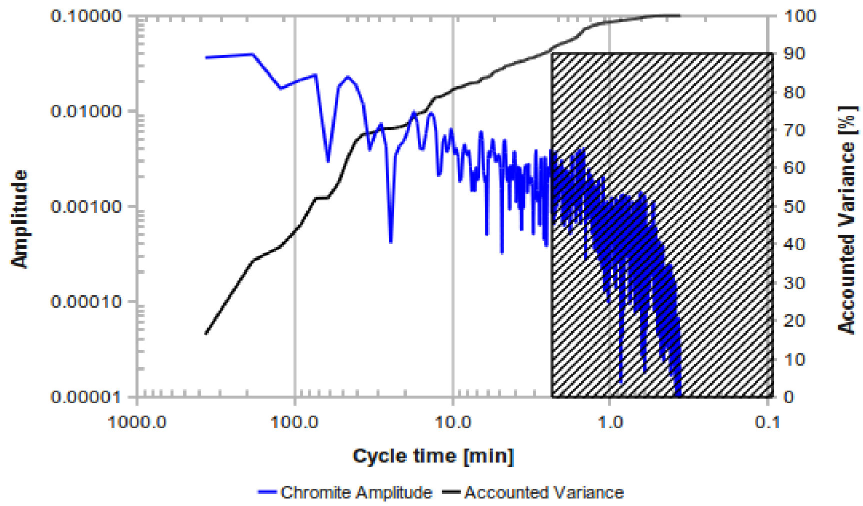

Figure 3 – Fourier transform and accounted variance for chromite

For the same stream, a Fourier transform was drawn up for the chromite results over the same 4 hour period. Interestingly, the dynamics of the chromite is faster than that of the PGMs. Chromite does not float, but enters the concentrate stream through entrainment (water recovery). The absolute maximum sample interval time for the chromite is half of 2.7 minutes: 1.4 minutes.

Case study 2: Feed and final concentrate grades of copper sulphide and copper oxide (acid soluble copper) from a copper concentrator in Zambia

Lee et al. (2008) documented that many copper sulphide mines around the world have significant copper oxide ore reserves associated with the larger primary copper sulphide deposit. The relationship between the two fractions of copper is not fixed. With the availability of data distinguishing between the copper contribution associated with oxide ores and sulphide ores, process control can be enabled to optimize copper recovery in real-time.

With the availability of analyzers installed on the feed and final concentrate lines, the dynamics of both these streams were investigated.

Figure 4 illustrates feed stream data made available online to operators and metallurgists for the copper associated with oxides, the copper associated with sulphides and also iron.

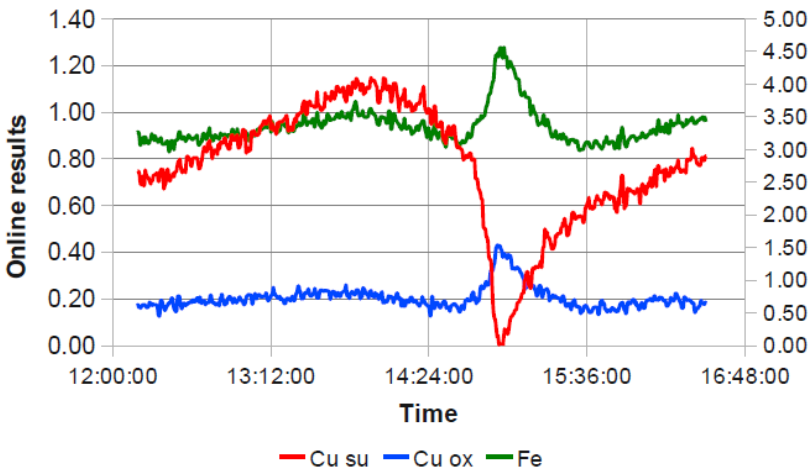

Figure 4 - SCADA online results for Cu (sulphide), Cu (oxide) and Fe in the feed stream

It is expected that the dynamics of a feed stream will be slower than that of the product of a separation process and is mainly a function of variation in plant feed ore and liberation (as diffuse reflective spectroscopy is an optical method).

Very interesting to note from figure 4, is the process upset between 14:30 and 15:30 where a spike of oxide gangue mineral was introduced to the process.

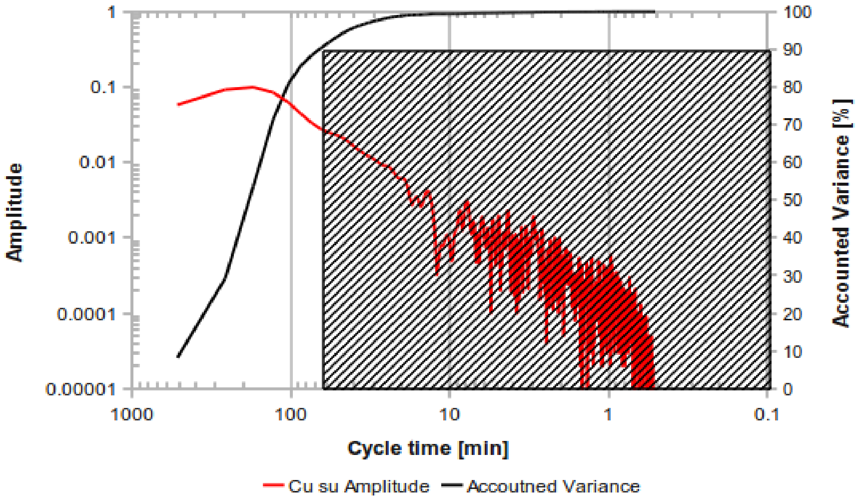

Figure 5 - Fourier transform and accounted variance for the Cu (sulphide) in the feed stream

From figure 5, 90% of the variance is accounted for at an interval time of 64 minutes. For control purposes, it is therefore necessary to measure the copper associated with the sulphide ore at a sampling interval time of less than 32 minutes.

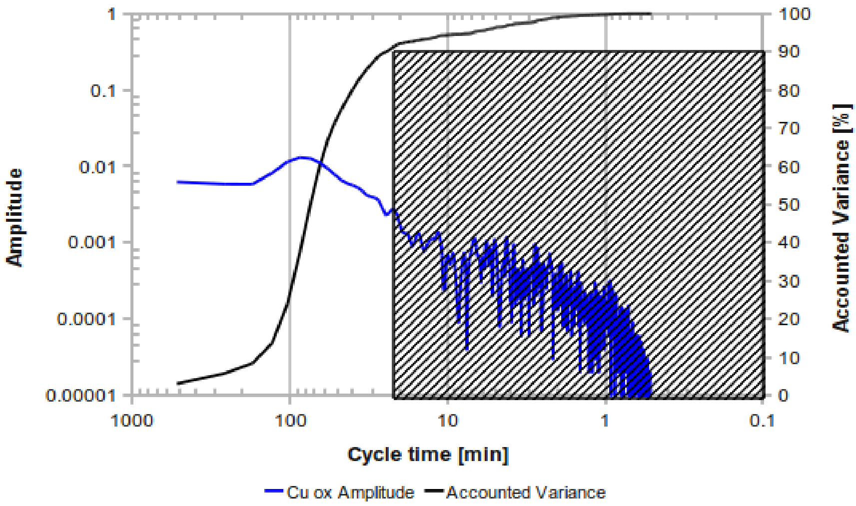

Figure 6 - Fourier transform and accounted variance for the copper (oxide) in the feed stream

The copper associated with oxide ores require a sampling interval time of less than12 minutes as 90% of the variance is accounted for with a sampling interval time of 24 minutes.

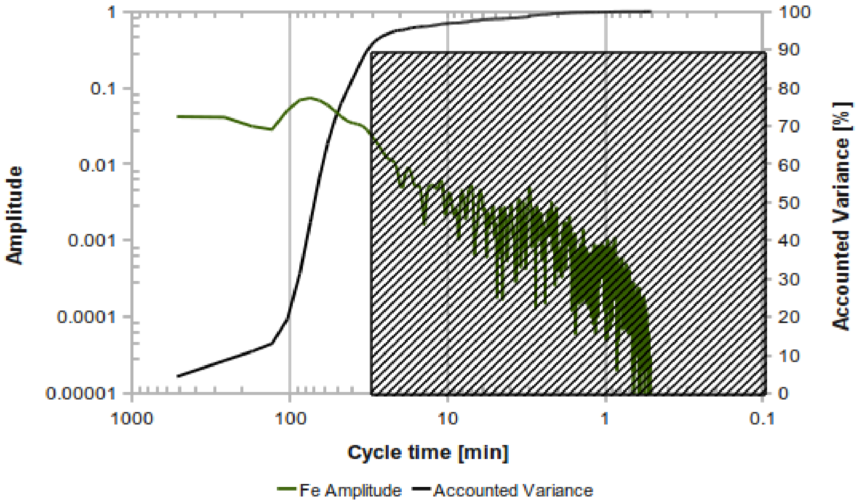

Figure 7 - Fourier transform and accounted variance for the iron in the feed stream

The variation of the iron content in the flotation feed necessitates a sampling interval time of less than 15 minutes for use in process control.

Figure 8 illustrates the SCADA results for the three components in the final concentrate stream.

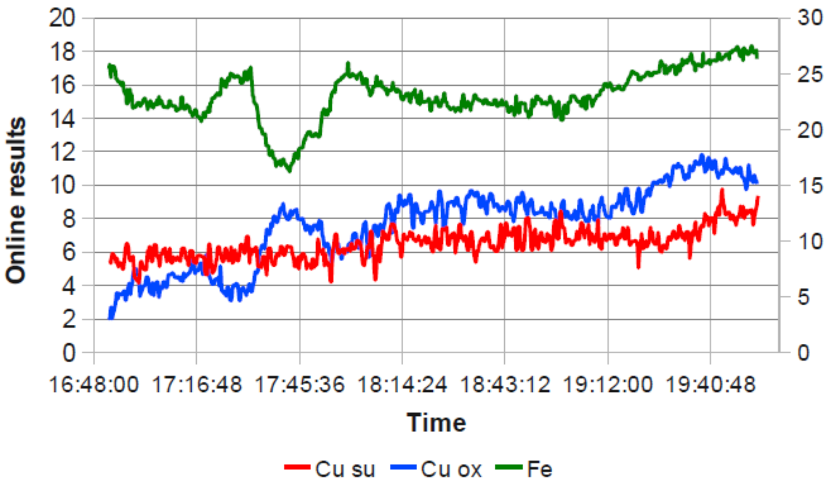

Figure 8 - SCADA online results for Cu (sulphide), Cu (oxide) and Fe in the final concentrate stream

The flotation process separates sulphides from gangue minerals. The dynamics of the copper associated with the sulphides is therefore much faster than that of the copper associated with the oxides.

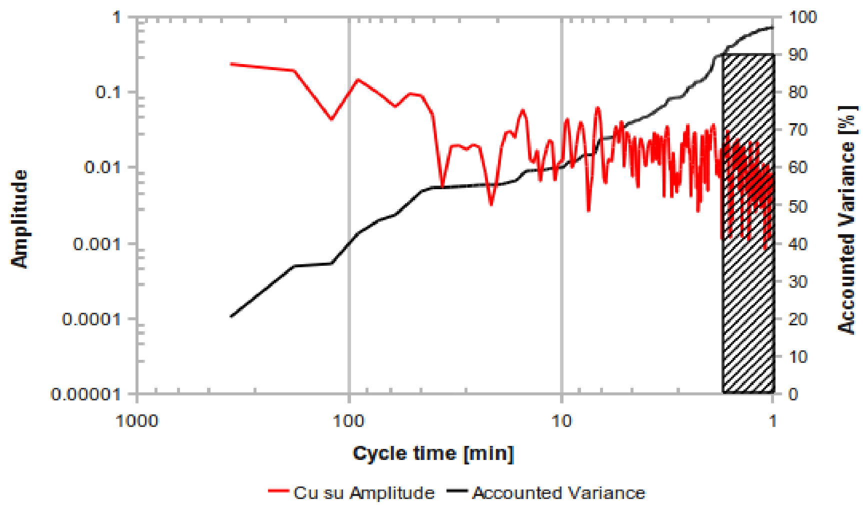

Figure 9 - Fourier transform and accounted variance for the Cu (sulphide) in the concentrate stream

As expected, the dynamics of the copper associated with the sulphide minerals is much faster for the product stream than for the feed as illustrated in figure 9. A sampling interval time of 1.8 minutes accounts for 90% of the variance and therefore the data interval time required for process control is less than 1 minute.

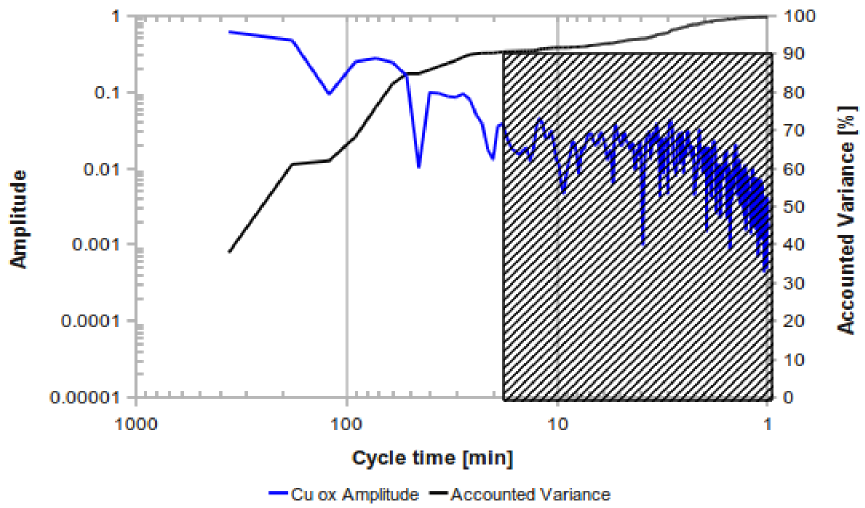

Figure 10 - Fourier transform and accounted variance for the Cu (oxide) in the concentrate stream

The copper associated with the oxide minerals in the concentrate stream have similar dynamics to the same component in the feed stream. The required sampling interval time for process control is also less than 12 minutes.

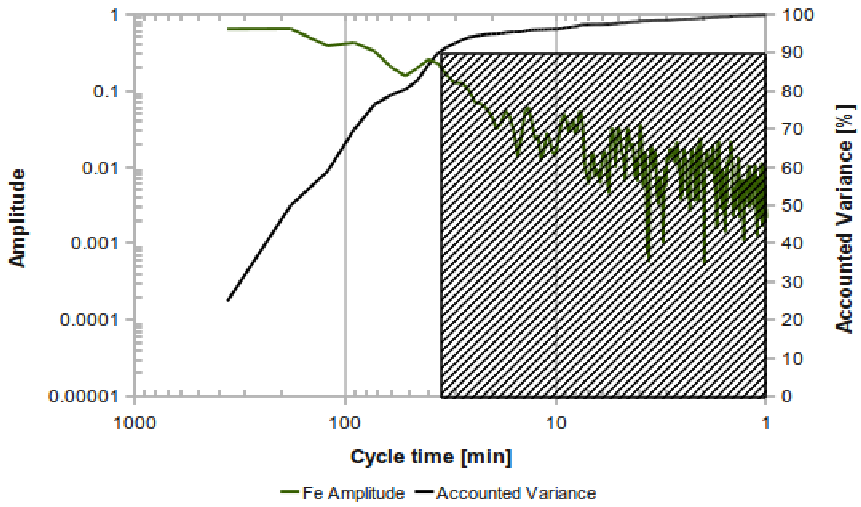

Figure 11 - Fourier transform and accounted variance for the Fe in the concentrate stream

Similarly, the sampling interval time required for controlling iron on the final concentrate stream is less than 18 minutes.

Case study 3: Chromite grade and two fractions of particles size from the flotation feed stream at a Platinum concentrator in South Africa

A very interesting application was also investigated where two fractions of particle size were measured on the flotation feed stream at a platinum concentrator. It is one of the important key performance indicators and is also referred to as the grind.

Apart from the grind, the chromite in the stream was also investigated. The particular concentrator treats a blend of Merensky and UG2 ore types of which the UG2 has a greater contribution of chromite.

Having a real-time measurement of both the grind and the chromite enables the manipulation of process variables to ensure optimum PGM recovery.

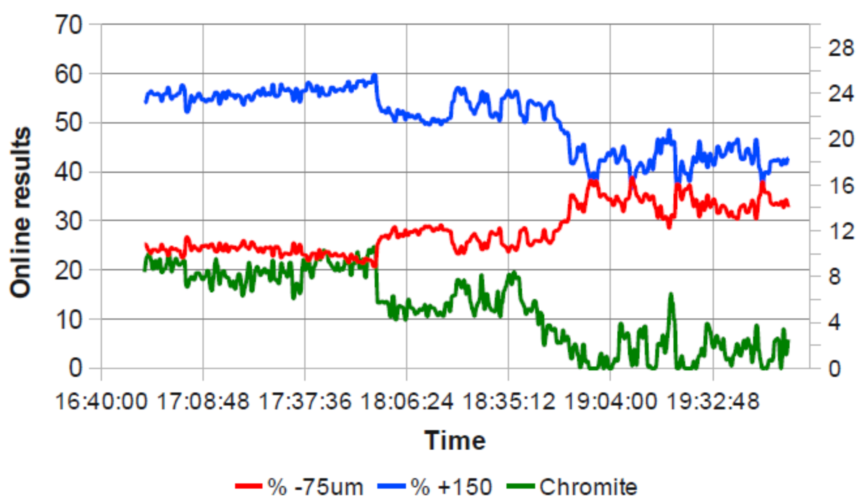

Figure 12 - SCADA online results for %-75um, %+150um and chromite in the feed stream

Note from figure 12 that with a higher fraction of Merensky ore, which is a harder rock type, the finer grind (% -75 microns) increased as expected.

From figure 13, 90% of the accumulated variance is accounted for at a sampling interval time of 14 minutes. Therefore, the required sampling interval time for process control is less than 7 minutes. Similarly, the sampling interval time for the coarser fraction is also 7 minutes.

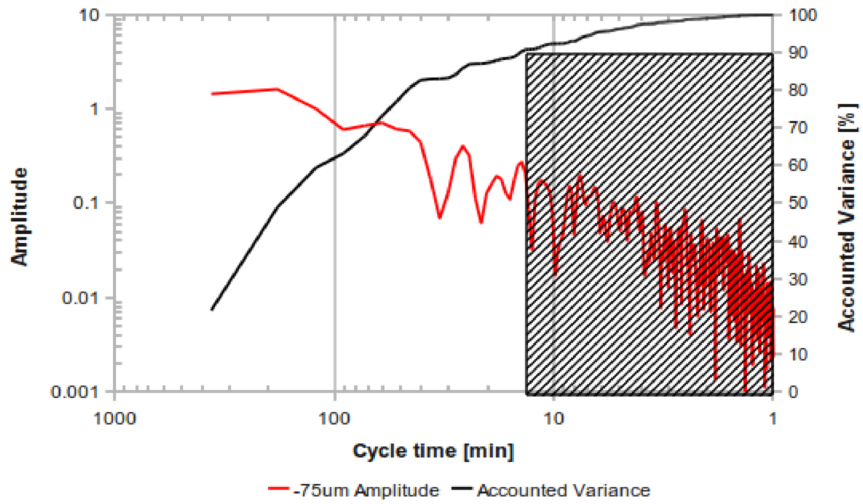

Figure 13 - Fourier transform and accounted variance for the % -75 um in the feed stream

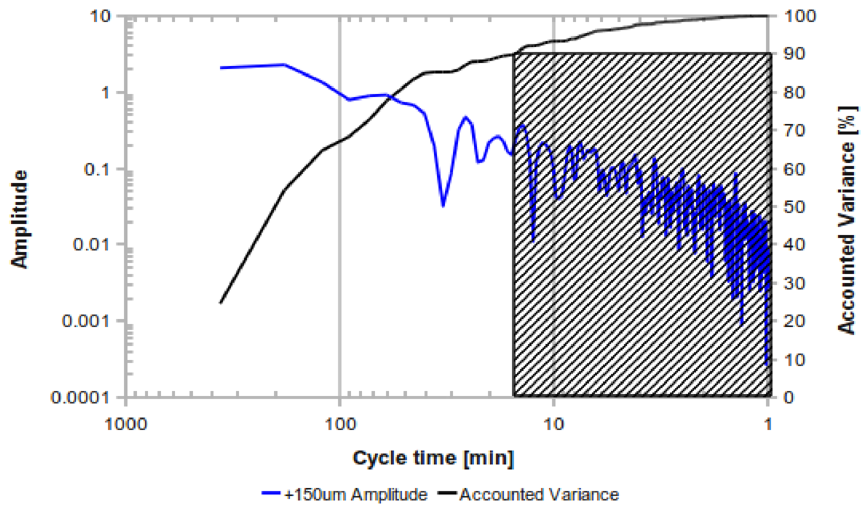

Figure 14 - Fourier transform and accounted variance for the % +150 um in the feed stream

Due to the blend of ore types, it is not unexpected that the dynamics of the chromite in the feed stream is relatively high. From the collected data, 90% of the variance is accounted for at sampling interval times of less than 9 minutes. If the chromite composition is required for process control, data need to be sampled at interval times of less than 4.5 minutes.

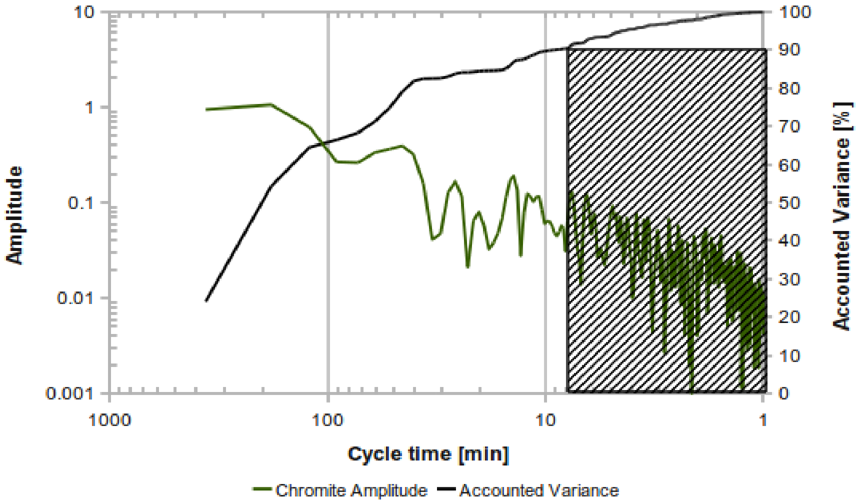

Figure 15- Fourier transform and accounted variance for the chromite in the feed stream

CONCLUSIONS

Evident from the case studies investigated, the required sampling interval time is different for different process stages and components.

Controlling the PGMs and chromite in the product stream on platinum concentrators, typically requires sampling interval times of less than 4.5 minutes for the PGMs and 1.4 minutes for the chromite. Measuring the chromite in the flotation feed stream to ensure optimum process parameters accounting for varying ore types, require sampling intervals of less than 4.5 minutes.

The measurement of copper association in the flotation feed stream of a mixed ore copper concentrator allows adjustments to process parameters to ensure optimal processing. Copper associated with sulphides in the feed stream requires sampling interval times of less than 32 minutes and copper associated with oxides requires less than 12 minutes. In the final product stream, the sampling interval time required for process control decreases to less than 0.9 minutes for sulphide associated copper and remains at 12 minutes for oxide associated copper.

Mill control can be used to control the grind by changing mill operating parameters. Measurements made in the flotation feed stream at a platinum concentrator typically requires a sampling interval time of less than 7 minutes.

The results show that single stream analyzers are the only sensible options for these case studies, and multi-stream analyzers with sample times of more than 3 minutes would degrade the response of an automatic control system.

The value of single stream analyzers based on diffuse reflective spectroscopy has been realized and widely implemented in the sulphide flotation industry in South Africa and also in other countries.

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