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Application of an integrated control system for continuous monitoring of sampling performance

C.S. Adams[a], K. Potts[b] and T. Neidel[c]
[a]Craig Adams – Senior Technical Advisor, FLSmidth Pty Limited, 58-60 Dowd Street, 6106 Welshpool WA Australia.
Email: craig.adams@flsmidth.com
[b]Kenneth Potts – Design Engineer, FLSmidth Pty Limited, 58-60 Dowd Street, 6106 Welshpool WA Australia.
Email: kenneth.potts@flsmidth.com
[c]Tore Neidel – Engineering Manager, FLSmidth Pty Limited, 58-60 Dowd Street, 6106 Welshpool WA Australia.
Email: tore.neidel@flsmidth.com

There is a need in the mineral processing industry for an integrated system to monitor and control ISO compliance of sample stations. This paper discusses development and application of a control system toolbox to meet this need and to deliver complete ISO compliant functionality. Traditionally, automated sampling systems rely on generic equipment control standards to operate the individual sampling components. The design of the sampling equipment in these systems may comply with ISO requirements, but does the integrated system also comply? This paper describes application of a standardized software library that integrates the requirements of ISO sampling standards with customized equipment control units via a supervisory control module, to bridge this gap. These libraries are based on many years of combined sampling, electrical and control engineering experience. This appropriate blend of expertise has enabled us to seamlessly integrate standalone, automated, sampling devices into ISO compliant sampling systems. All components have well-defined interfaces as well as common functional control and reporting mechanisms. The result is a fully integrated sample station that performs as an interconnected, ISO compliant quality system. The benefit of a standardized and integrated sample station is consistent production of reliable and accurate results. Trustworthy sample data gives Quality Assurance and Quality Control analysts, technicians and plant management a high degree of confidence that they have a full understanding of their material's properties and commercial worth. Confidence in sampling results is essential as the quality of the material is inexorably linked to a company's reputation as a reliable supplier of quality products and, ultimately, to their bottom line.

Introduction

Sampling systems can be designed, manufactured and installed so as to meet the requirements of ISO standards and Theory of Sampling (TOS).

However the operation and monitoring of these sampling systems is then left to the user to evaluate and monitor the performance of the sampling and to make changes as required to ensure continued unbiased performance. Too often the designers are asked to revisit installed systems to try to evaluate why the correct sampling protocol is not being achieved. The investigation often concludes that vital parameters have been altered and the installed control system no longer is able to produce the required primary or subsequent sampling.

In order to try to control the sampling process with continual monitoring of the necessary sampling parameters FLSmidth Pty Ltd embarked on a development program to integrate the various controls into a total control system which could provide the feedback necessary to instil operator confidence in the samples taken.

In 2014, the FLSmidth sampling development team designed and constructed a suite of software components that:

- Provided sample station control that follows TOS guidelines and complies with ISO standards
- Accesses software libraries modelled on the FLSmidth range of sampling products
- Ensures safe operation of the equipment
- Ensures robust and reliable performance of the equipment and system
- Provides user-friendly configuration and operation

The conceptual design of this software was presented at the Sampling 2014 conference in Perth, Australia, titled: "Control & Monitoring of International Organization for Standardization Compliance for Industrial Sampling Systems" – T Neidel, C Adams and R Shaw. This conceptual design has now been implemented in a fully automated Mineral Sampling System at a customer's iron-ore shiploader installation. A second system has been constructed and waiting commissioning and another two systems are scheduled for completion later this year.

This paper presents and discusses the performance and operation of this Integrated Sampling Control System (ISCS) and demonstrates the advantages in its use.

Integrating the Sample Station and the Control System

The sample system mechanical layout and sampling process was designed in conjunction with the customer to provide a sampling protocol in accordance with *ISO 3082 Iron Ore – Sampling & Sample Preparation Procedure* (ISO 3082).

The sample system mechanical layout design followed acceptable sampling procedures selecting and integrating proven equipment into an ISO compliant process. The control system was built using function block libraries which allow station control system development to be simply a matter of selecting the function block components in a Lego® building block methodology, where a system is constructed by connecting pre-built building blocks. This minimises re-design and programming errors while promoting a well-defined structure with a consistent interface. In-built simulation functionality provided an excellent mechanism for off-line device and sequence testing providing a high degree of confidence before commissioning the system.

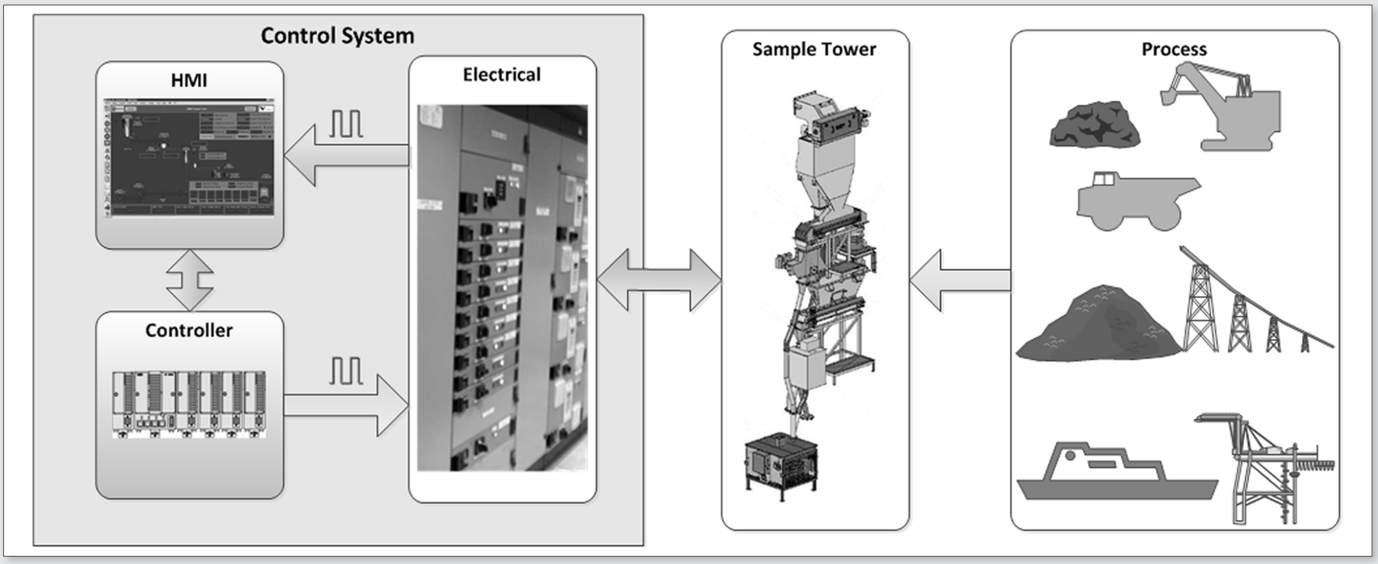

Figure 1. (a) Control system architecture (b) Sample tower and (c) Process schematics

Standard design principals were applied to the development of the ISCS using three standard FLSmidth products;

- ECS® (Expert Control and Supervision) – is a windows-based Human Machine Interface (HMI) for plant supervision and process control.
- Metis™ (Multi-Engineering Tool and Information System) is based on an object oriented control methodology especially designed for the cement and minerals industry. ACESYS is a standard library for consistent and reliable PLC programming.
- ACESys® (Adaptable Control Engineering System) – is a propriety tool for alignment of best practice engineering standards.

The control system uses a local, dedicated sub-control system to provide machine level control of sampling tasks. The system contains many advanced functions for trending, troubleshooting and remote reporting.

Emphasis was given to

- Safe operation
- Repeatable control

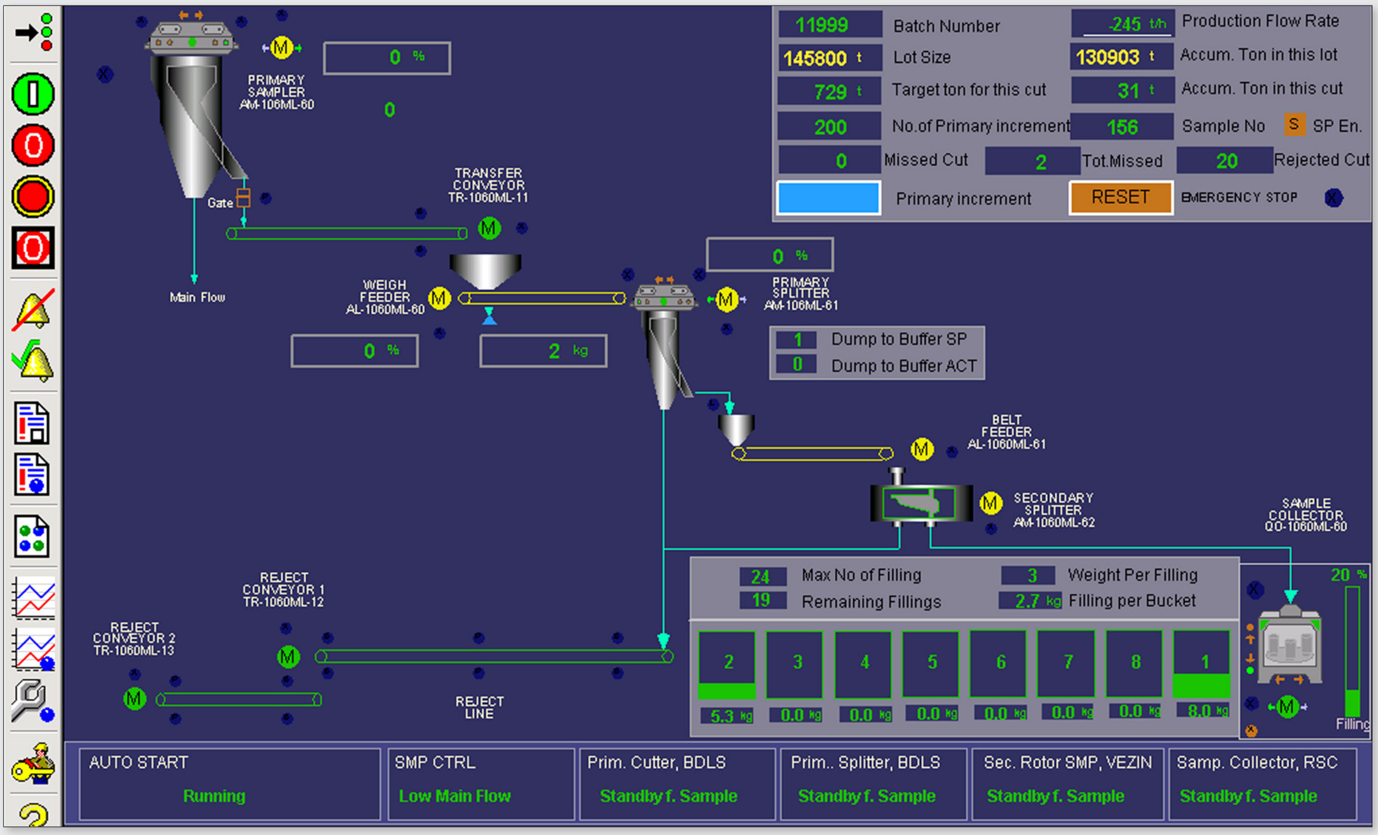

Figure 2. ISCS HMI graphical overview screen

- Adaptable to the customers process
- Ease of use and maintenance
- Full lifecycle support
- ISO 3082 Compliance

Figure 1 shows the relationship of the control system to the sampling station equipment and the ship loading process.

One of the features of the ISCS is the ability to provide transparency of the sample system activities. The Human Machine Interface (HMI) system is the window into the ISCS. It provides a series of real-time animated screens that display the current and historical status of the sample station. The benefits provided are;

- Monitor the operation and performance of the sampling system in real time – typical graphical overview screen is illustrated in Figure 2.
- Provide alarm and warning information – the notification can be related to;
  - ISO violations
  - Sampling equipment failures
  - Process events – such as a chute blockage
- Provide information on how to rectify faults

Alignment with ISO standards

While ISO standards mostly deal with the mechanical aspects of the collection and handling of a sample, there is other functionality that the control system must take into account. Therefore the software development must also consider the alignment to and application of ISO rules.

The ISCS control system we are describing in this paper is generic to the mineral sampling industry, but the discussion and examples relate to a system installed at an iron-ore ship-loader installation where the software was tailored to meet *ISO 3082 Iron Ore – Sampling & Sample Preparation Procedure*. The control system can be adapted to any other sampling standard.

The iron ore control system software has the following ISO 3082 monitoring and control features embedded in the code:

- Sampling methodology
- Cutter velocity control
- Safety of operations
- Robustness of sampling installation

Sampling Methodology

The top level function of the control system software is the selection of the appropriate sampling method.

The steps for establishing a sampling scheme are mostly decided by the sampling design group. However the control software uses ISO3082 to make decisions determining the number of increments and timing of the intervals between initiating a primary increment, based on QA/QC or production manager input of lot size and quality variation.

The design of the system is such that the initiation and handling of a sample lot is automated, eliminating operator-entry or lot- calculation errors.

For a customer specified lot, the lot information must be provided to the sample station control system. When the lot ID and size are transferred to the system (via the Plant Control System or a Laboratory Management System) a new lot/batch is initiated.

The number of primary increments and the tonnage target are automatically calculated by the system and then the tonnage accumulators are reset.

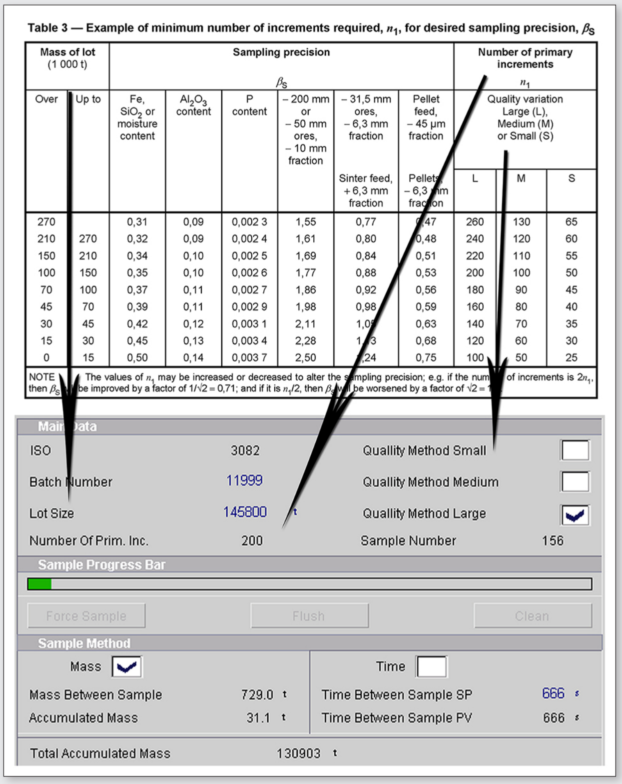

Table 3 — Example of minimum number of increments required, n_1, for desired sampling precision, β_S

Mass of lot (1 000 t)		Sampling precision β_S						Number of primary increments n_1		
								Quality variation Large (L), Medium (M) or Small (S)		
Over	Up to	Fe, SiO_2 or moisture content	Al_2O_3 content	P content	– 200 mm or – 50 mm ores, – 10 mm fraction	– 31,5 mm ores, – 6,3 mm fraction / Sinter feed, + 6,3 mm fraction	Pellet feed, – 45 μm fraction / Pellets, – 6,3 mm fraction	L	M	S
270		0,31	0,09	0,002 3	1,55	0,77	0,47	260	130	65
210	270	0,32	0,09	0,002 4	1,61	0,80	0,48	240	120	60
150	210	0,34	0,10	0,002 5	1,69	0,84	0,51	220	110	55
100	150	0,35	0,10	0,002 6	1,77	0,88	0,53	200	100	50
70	100	0,37	0,11	0,002 7	1,86	0,92	0,56	180	90	45
45	70	0,39	0,11	0,002 9	1,98	0,98	0,59	160	80	40
30	45	0,42	0,12	0,003 1	2,11	[illegible]	0,63	140	70	35
15	30	0,45	0,13	0,003 4	2,28	[illegible]	0,68	120	60	30
0	15	0,50	0,14	0,003 7	2,50	[illegible]	0,75	100	50	25

NOTE The values of n_1 may be increased or decreased to alter the sampling precision; e.g. if the number of increments is $2n_1$, then β_S will be improved by a factor of $1/\sqrt{2} = 0,71$; and if it is $n_1/2$, then β_S will be worsened by a factor of $\sqrt{2}$ = [illegible]

Figure 3. Sampling Scheme – Main Data Screen

The control system calculates the number of primary increments based on Table 3 of ISO 3082 (Figure 3).

ISO 3082 defines three methods for sample collection:

- 6.1 Mass-Basis Sampling – where increments shall be taken at fixed mass intervals
- 6.2 Time-Basis Sampling – where increments shall be taken at fixed time intervals
- 6.3 Stratified Random Sampling within Fixed Mass or Time Intervals – where a randomized sampling interval is introduced to either the mass or time based schemes in 6.1 or 6.2

The client's preference was for Mass-Basis Sampling and the control system initiated the primary sampler from an upstream belt weigher (weightometer) to provide the ore mass flow rate required. Time-Basis sampling was also incorporated as a backup method for the Mass-Basis Sampling in case the upstream weightometer failure. The software provides the ability to switch from mass based sampling to a time based regime (and back) by the selection of a check box on an operator interface faceplate. All sample station tuning and configuration parameter changes are protected by a password control scheme.

The first increment of a new lot is taken at a randomly generated target tonnage after commencing the sampling operation (in accordance with 3082 – 6.1.4). Subsequent increments are taken at the fixed mass intervals until the entire lot has been processed.

The installation uses a variable speed cutter as required by the standard to match the cutter velocity to the mass flow rate. The system has provision to check the weight of the primary increment to determine if the increment is within the ISO 3082 specified 20% tolerance. If the primary increment is Out Of Specification (OOS), the sample is rejected and an immediate resample is initiated.

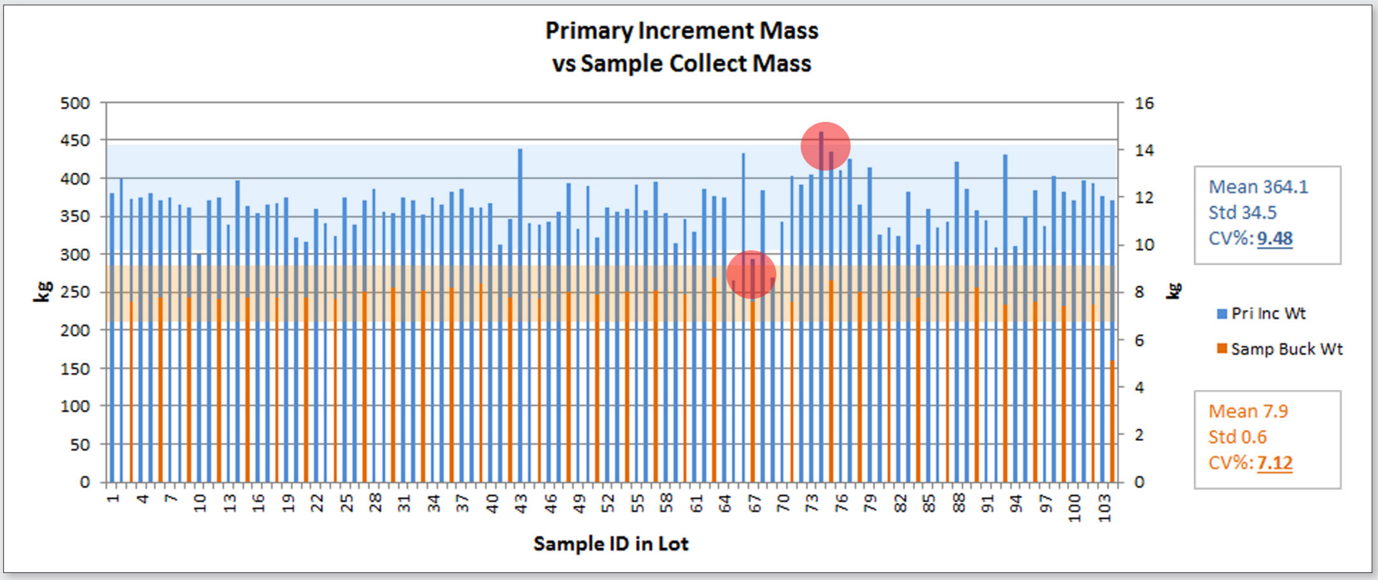

Figure 4. Primary increments vs. sample bucket mass – selected OOS samples highlighted

Figure 4 shows data from the installed site of the catch weights of 104 primary increments, with the 370 kg increment weight target, and the blue lines indicating the 20% tolerance level which was exceeded by the OOS samples that were rejected. Also displayed is comparative data showing the sample mass collected in the sample bucket, target mass 8 kg, the orange lines indicating the 20% tolerance level.

Cutter Velocity Control and Monitoring

The ISO standard defines in detail the design of the cutter geometry and its positioning for the collection of the primary increment. Details of the mechanical design and their meticulous application of the ISO standards are outside the scope of this paper. However section 5.1.4.1 of ISO 3082 covers the velocity of the primary cutter moving through the falling ore stream. The installed control system software provides a user interface screen (faceplate) for velocity control. The object is to minimise Delimitation Error (DE), hence eliminating bias in the sampling process. (Refer to "Sampling of Particulate Materials Theory and Practice" By Pierre Gy, Chapter 17, on Increment Delimitation Error).

The ISO standard also defines the mass of the increment to be taken (mechanically or manually) by a cutter-type sampler from the ore stream at the discharge end of the conveyer belt (ISO 3082:2009 – 5.1.4.1) by the following equation:

$$m_{\mathrm{I}} = \frac{q^{\prime}1}{3{,}6v_c}$$

The relationship between cutter velocity and the production ore flow for a defined catch weight (in this case 370 kg) as is shown in Figure 5.

The actual velocity deviation through the ore stream can be monitored by a Linear Sampler monitoring system and it reports the

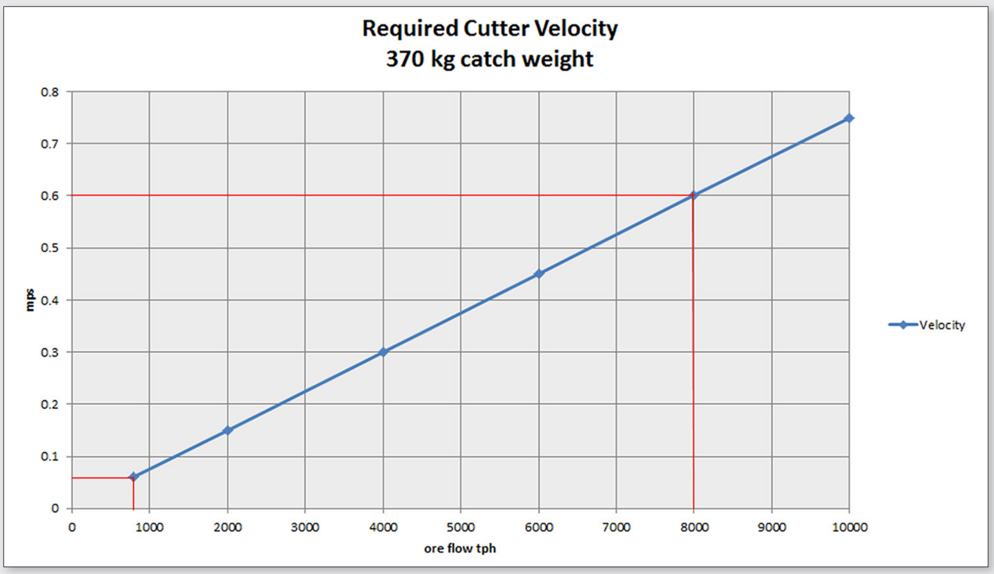

Figure 5. Proportional VSD speed vs. ore flow rate

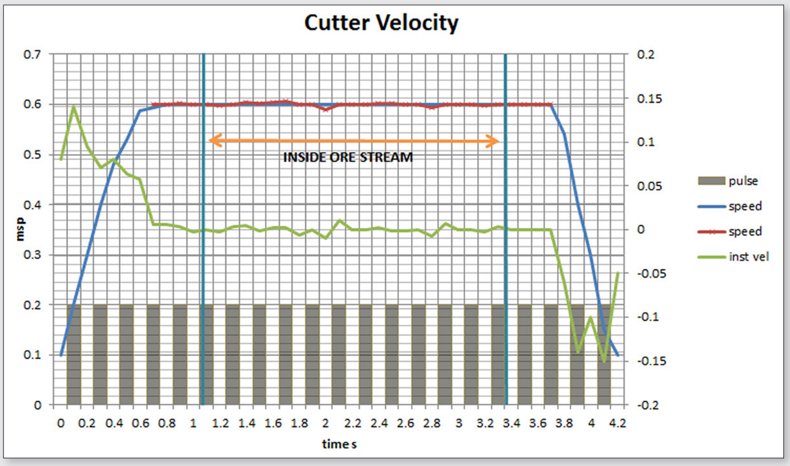

Figure 6. Cutter velocity vs. time

consistency of the cutter spoon's velocity through the ore stream and displays a reading of the sampler's motion (as a percentage of the average travel against the set point speed).

Figure 6 shows the cutter velocity over a period of 4.2 seconds (at 100 msec intervals).

Operational Safety and Standards

Operational safety is of critical importance to industrial operations and the control system allows observation, monitoring and control of the sample station from a safe environment. The ISCS aligns with ISO 3082 Section 7.2 Safety of Operations, and also incorporates all necessary safety standards as required by international regulations.

Robustness of the Sampling Installation

Failure of sampling systems is often a result of poor maintenance. Cutter blades are not replaced, cutter speeds not checked and sample masses not recorded. Bias tests on A and B primary samples are only checked at significant audits. While the ISO 3082 refers to the mechanical robustness of the sampling equipment and this should also be applied to the control and monitoring process.

Based on reliability data and experience the control system was strengthened by incorporating the following features:

- Redundant Central Processing Units and power supply
- Sampling equipment retry method (example – if a gate is blocked by a rock; retry to open and close the gate to dislodge the rock. These are common occurrences and should not cause the system to fail on the first attempt).
- Function to re-sample primary increment if OOS – in compliance with ISO 3082 6.1.1. Part C.
- Maintenance scheduling based on operation time.

Development Challenges

Bridging the gap between theory and reality presents challenges such as aligning the timing of the ore flow rate on the feed conveyor belt to the activation of the primary sampler. The production belt weightometer, being 53.7 meters before the primary sampler, with a belt speed of 3.72 meters/sec, resulted in a flow rate lag of 14.4 seconds.

$$t = \frac{53.7 \text{ m}}{3.72 \text{ mps}} = 14.4 \text{ seconds}$$

The inconsistent flow rate presented a problem for the mass based sampling method, raising the question of how to align the cutter velocity to the instantaneous flow rate. The challenge was

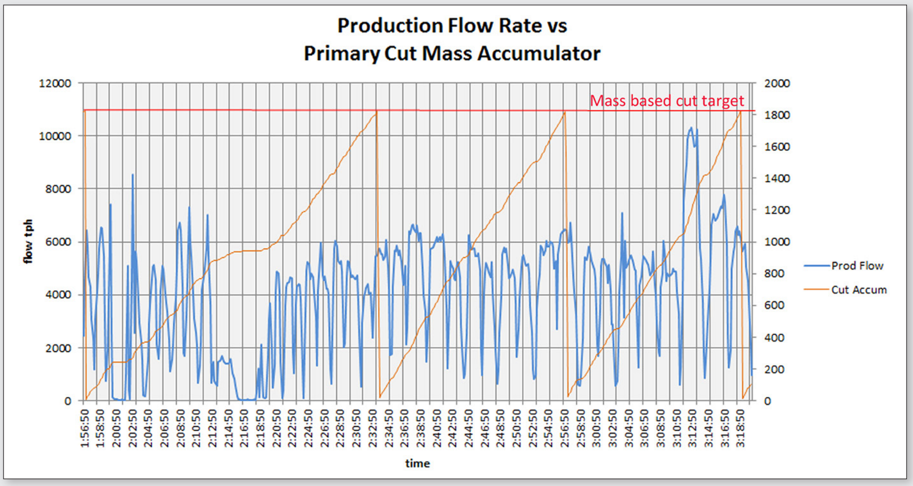

Figure 7. Production flow – note highly variable feed flow rate

Table 1. Device data blocks for sample tracking of primary sampler and splitter

Name	Data Type	Attributes	Description
MinSampleNo	Dint	retain hidden	Minimum Sample Number
MaxsampleNo	Dint	retain hidden	Maximum Sample Number
NoOfMainCuts	Dint	retain hidden	Number of Main Cuts
Weight_SP	Real	retain hidden	Weight Setpoint
Weight_PV	Real	retain hidden	Weight Actual
Weight_Tolerance	Real	retain hidden	Max Allowed Weight Tolerance (kg)
TotAccMass	Real	retain hidden	Total Accumulated Material Current Batch (kg)
BatchNo	Dint	retain hidden	Batch Number
AB_Cut	Bool	retain hidden	0 = A-cut, 1 = B-cut
LogType	Int	retain hidden	0 = OK, 1 = Weight Fault

resolved providing a consistent primary increment mass to meet the ISO standard CV requirement. Figure 7 shows the varying flow rate. As explained earlier timing is critical to ensure the cutter velocity is matched to the actual flow rate of ore, as it enters the cutter spoon, to ensure that the correct sample mass is collected in the increment as given by the following formula.

Sample Data Tracking

Event logs are an important requirement of any control system. The Integrated Sampling Control System provides an audit trail of sampling activities, sample masses and events. The software collects relevant sample data at every stage of the sampling process. The sampling process data is event driven and provided in real-time.

The ISCS also provides interpretive graphing of data so that trends can be monitored for sampling process analysis and diagnostic information.

Benefits of an Integrated Sampling Control System

Generally there are two common methods of programming and interfacing the vendor package to the plant a mineral handling or processing control system. They are:

- Typically during the construction of a mineral handling or processing plant, the principal contractor integrates the sampling system into the required area of the plant. Similarly the principal contractor integrates the control of the sample system into the plant control system; but this may introduces risk, due to the generic engineering integrator having limited sampling knowledge or functional understanding of sampling requirements.
- The sampling equipment designer provides an integrated packaged solution, where control is implemented with the sampling system. This methodology takes into account the complexities of sampling systems, conformance to sampling standards and the application of the manufactures expert knowledge.

The equipment designer is the expert in understanding and controlling the mechanical components and processes of their products. The operation of a sampling system and the control of the sampling equipment **is *not* a material handling application**. It is far more complex, as has been demonstrated in this paper. Generic control system engineers have, at best, a limited understanding of TOS and/or ISO requirements and therefore find it difficult to provide and integrated control system for the sample station.

A key benefit of correct integration of the sample station and control system is that the system designer is able to provide support (including remote support) over the life cycle of the system.

Conclusions

The Integrated Sampling Control System offers a reliable, safe and repeatable control system that allows operators to monitor and control the sampling parameters in accordance with TOS and ISO 3082 guidelines.

It provides the operator with:

- Security that the sampling system operates as it was designed and installed, and provides an integrated and accountable quality system.
- Detailed primary sample information.
- Correct sample increments for variable lot sizes.
- Monitoring of cutter velocity
- Advice to ensure programmed maintenance is performed.
- An audit trial of all sampling operations.

The ISCS can give the confidence when asked "Is your sampling system ISO 3082 compliant?"

Acknowledgements

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