Process Control in metallurgical plants—From an Xstrata\(^1\) perspective\(^\star\)

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Abstract

Some history and modern practice of Process Control in metallurgical operations is reviewed. Clearly the early deliverables from the pioneer days in the 1950s through to the 1970s and early 1980s were under-appreciated. The discipline has since grown into a more visible, sophisticated and accepted practice as a result of the assembly of appropriately recruited and trained individuals and teams, who have successfully negotiated deliverable projects that impact all metallurgical performances beyond early milling processes. The skill set in these individuals and teams essentially includes organisational behaviour in addition to their specialist technical attributes. A strong network to internal and external specialists and experts is essential. Furthermore, instrumentation and control technology has improved immensely. The challenge in the current modern practice is to win support of senior management in operations for the project cost, schedule and deliverables of Process Control. Once gained, this acceptance then amounts to the logistics of project scope and delivery—a track record well-demonstrated by the Xstrata Process Control Group.

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Keywords: Process Control; Instrumentation; Automation; Optimise; PROFIBUS; AMIRA; PID; ExperTune; PlantTriage; Model Predictive Control; Multivariable; Connoisseur; MonitorMV; FloatStar; Multivariate Modelling; PCA/PLS; Fault Detection; FieldCare; Process Mineralogy; SAG; ASRi; XRF; Camera Imaging; Grinding; Flotation; Electric Arc Furnace; Xstrata; Xstrata Process Support; Xstrata Technology; Metso minerals

1. Introduction

The objective of the third plenary lecture is to present the state of the art of applied automatic control and information processing in one or several MMM fields (physical metallurgy, mineral processing, extractive metallurgy, and mining). Mineral processing and extractive metallurgy are the selected MMM fields for this discussion.

In this paper, automation is understood in a broad sense including: measurement and instrumentation; process modeling and simulation; process monitoring and data reconciliation; data mining and multivariate statistics; fault diagnosis and fault tolerant control; Process Control; monitoring of product quality and control performance; off-line and on-line process optimisation; maintenance scheduling and production planning; as well as AI methods like: expert systems, neural networks, fuzzy control.

To address as many of these areas of automation as possible, this paper divides into the following sections:

1. Introduction and Process Control definition, objective and cycle
2. Elements necessary for successful Process Control in mineral and metallurgical plants, covering:
   2.1. People—control/process knowledge
   2.2. Tools—instruments; systems; technology
   2.3. Actions—support, management, technology transfer

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\(^1\) Xstrata is a global diversified mining group with its headquarters in Zug, Switzerland. Xstrata's businesses maintain a meaningful position in seven major international commodity markets: copper, coking coal, thermal coal, ferrochrome, nickel, vanadium and zinc, with recycling facilities, additional exposures to gold, cobalt, lead and silver and a suite of global technology products. Xstrata Group’s operations and projects span 18 countries: Argentina, Australia, Brazil, Canada, Chile, Colombia, the Dominican Republic; Germany, New Caledonia, Norway, Papua New Guinea, Peru, the Philippines, South Africa, Spain, Tanzania, the USA and the UK. Xstrata employs approximately 43,000 people, including contractors.

\(^2\) Xstrata Process Support (XPS; previously known as the Metallurgical Technology Group) is an expert group based in Sudbury (Ontario) Canada and at other various Xstrata operating sites. Through the four business areas of: Process Mineralogy, Extractive Metallurgy, Process Control and Materials Technology, XPS provides support to Xstrata commodity businesses, with an objective of providing quality technical expertise for operational support, growth initiatives and strategic development.

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E-mail address: pthwaites@xstrataprocesssupport.ca.
3. XPS Process Control philosophy summary
4. The ‘near term’ outlook
5. Conclusions

Examples and case studies are briefly presented throughout the paper to illustrate the points being made. Acknowledgements and references follow after the conclusions section.

1.1. Process Control definition

McKee (1999) states:

“Process control is a broad term which often means different things to different people. For the purposes of this (AMIRA) review, process control is considered as the technology required to obtain information in real time on process behaviour and then use that information to manipulate process variables with the objective of improving the metallurgical performance of the plant. This was, in fact, the objective of the early (metallurgical) control systems.”

Furthermore, he goes on to state:

- “Process Control is a long-established technology.”
- “Within the minerals industry, single loop pneumatic controllers became commonplace in the 1950s.”
- “By the mid 1960’s, process control was seen by the mineral industry as a technology which offered a great deal in terms of potential improved plant performance.”
- “Work on flotation control systems began in the early 1970’s based upon the availability of on-stream analysis data.”
- “Although the flotation control task was inherently more difficult than for grinding, there were many promising flotation control systems around the world in the mid to late 70’s” (and early 80’s).

“Thus, all the elements necessary for successful process control in mineral plants were known and largely available (over) 20 years ago, and were:

- **Instrumentation**
- Control hardware and software
- A growing understanding of process behaviour and dynamics
- Operator interfaces providing communication between operator, the system and the process
- An understanding for the absolute necessity for good instrument maintenance and the capability to perform it
- An understanding of the need for skilled personnel to develop/maintain control systems
- Proven successes of many systems
- Enthusiastic support of management for process control
- The active and productive involvement of research groups working with enthusiastic operations personnel.”

Although it is now several years later, these key elements have been selected to be discussed in this paper, as they are also seen to be very relevant to the approach of the XPS Process Control Group.

The goal of the XPS Process Control Group is plant Process Control for Operational Performance Excellence. The key elements to achieve this are summarised and addressed in Section 2, under the following sub sections:

2.1 People—control/process knowledge
2.2 Tools—instruments, systems, technology
2.3 Actions—support, management, technology transfer.

1.2. XPS overall Process Control objective

More recently, Thwaites and Lokling (2002) stated: “Installed instrumentation calibrated properly with appropriate resolution deadbands, and first order filters, is the basis for good proportional, integral and derivative (PID) control. This offers great potential to plants in reducing variability, opening up opportunities for optimisation through increased throughputs or reduced consumables (e.g. power, steel, reagents, etc.). Tools like Expert systems, Model Predictive Control (MPC) Multi-variable controls (MVC) with LP (linear program) optimisers, and even “higher-level” (cascade) PID controllers working on analyser information, provide the means to accomplish significant returns, but these are all dependent on a good/reliable instrumentation base and robust regulatory control.”

Fig. 1 is a general diagram, used for many years, to illustrate the overall Process Control objective for any key variable. Measure and understand the initial variability, stabilise and then optimise to the constraint of the process. Typically throughput benefits will come from an increase in the setpoint, and consumable savings will come from a decrease in the setpoint. Once these have been achieved it is important to ‘maintain the gain’ by ensuring the changes are robust, thus benefitting the plant.

In the process of stabilisation, it is very important to consider ‘the whole loop.’ ABB (Forsman, 1998) illustrated this very well, as shown in Fig. 2. Are there any loops in manual? There can be several reasons why controllers are in manual, for example: instrumentation; tuning; operator training; saturation and ability of control actions to influence the control variable, etc. Utilising tools like ExperTune (in 1999, selected by Control
Engineering as one of the best products of the year), at the commissioning stage, helps to identify the key issues preventing robust loop control.

Fig. 3 illustrates the critical mill bearing pressure measurements which required a basic filter so that the data is usable for control and better represents the real process issue. For sometime, following plant commissioning, all process signals were unnecessarily ‘noisy’ and it was not surprising that much of the plant’s control was manual! Alarming in this plant was also ineffective and poorly commissioned.

Additionally, Process Metallurgists/Engineers also need to be aware of ‘data compaction’ in the production management information system (PMIS). Over compaction, as over filtering, minimises the ability to ‘see’ the real process dynamic response.

The XPS Process Control Group is often requesting less compaction, while the IT support is often interested in maximum (and default) compaction. Similarly, PMIS systems should also, but often do not, capture important setpoints and outputs.

Referring back to Fig. 1 then, Process Control objectives can therefore be summarised as the management of tools and resources to: minimise process variation; optimise process performance; minimise (variable) costs; control product quality; and maximise safety.

In general a well established hierarchy (Jones, 1994/1996), as shown in Fig. 4, is followed. Economic returns considerably increase beyond loop regulatory control.

While process and area optimisation can have considerable financial returns, it is well recognised (and reported), by those
practising Process Control, that this can only be achieved by having a robust and solid regulatory lower level.

McKee (1999) states:

“Svedala (metso minerals) advocate a systematic approach to process control:

- start by defining what is important through an analysis of the process (an audit) to determine what is required and the level of control;
- understand the process and ensure the basics for good control are in place (e.g. instrumentation);
- match the installed system to the capability of the people available;
- recognize the on-going commitment required for success;
- with regard to the actual control, consider three levels as follows:
  - basic PID—via DCS or equivalent;
  - supervisory (cascade control, dead-time compensation, etc.—via DCS or equivalent);
  - optimising (e.g. expert system, adaptive)—via a package such as G2 or implemented within the DCS.”

However, it is important to understand that Process Control will not correct inherent design, instrumentation related flowsheet, and actual flowsheet problems in a plant.

‘There is a need to determine, and if necessary correct, the condition of the plant as a pre-requisite to control development. A good example is the importance of classifier operation and its effect on comminution circuit performance. Techniques exist (plant sampling, modelling and simulation) to audit the actual plant operation. Correcting plant limitations should be seen as a first step in the control approach.’ (McKee, 1999)

1.3. XPS process mineralogy

The hybrid Process Mineralogy group at XPS was started up in 1997. The key deliverable from this young discipline is to reliably formulate and demonstrate the optimum flowsheet for the processing of a given ore body (Lotter et al., 2002, 2003). This hybrid approach of sampling and statistics, geology, mineralogy and mineral processing (Fig. 5) outperforms conventional mineral processing because it describes the flowsheet in terms of representative sampling and minerals
instead of assays. Ongoing improvement in the concentrator operations, for example by Process Control projects that reduce variance, is thereafter benchmarked with Statistical Benchmark Surveying. The Process Control is easier to implement when a concentrator operation is on a Process Mineralogy platform, because the flowsheet allows for more responsive controls.

1.4. Effective Process Control cycle (for new processes/plants)

“A good implementation requires a well defined operating philosophy and an associated control strategy.” (McKee, 1999)

The XPS Process Control Group continually make the point that Process Control involvement during the early engineering stages (of a project) ensures effective start-up and the fastest turn-around to on-line process optimisation. Fig. 6 shows the Group’s ‘effective Process Control cycle’. This also fits in well with the Company’s (Xstrata Copper Canada) Six Sigma stage gate process (also shown in Fig. 6).

The Kidd Metallurgical Site Montcalm project was taken through the full Six Sigma stage gate procedure, ensuring all specified design criteria were met before proceeding to the next stage. This required the Process Control plan (Gillis & Lacombe, 2002) to be developed very early on in the process. Piping and Instrument Drawings (P&IDs) were first developed during 2002 and a detailed Process Control philosophy was written up as well. This philosophy detailed every loop, the expected flows, setpoints, operating ranges, limits, alarms, interlocks, etc.

The control philosophy generally specified only lower level (regulatory) loops with some cascade loops included where necessary. The approach taken was to have the regulatory loops ready for use at circuit start-up and to develop higher-level controls later as required. Following commissioning all control loops had been inspected, optimised and documented with the ExperTune software package, thus allowing the Process Engineers and Operators to focus on optimum process beneficiation, i.e. Operational Performance Excellence.

The XPS Process Control Group are often called into Plant processes after start-up to ‘correct and fix’ poorly commissioned process controls, sometimes after a considerable time period following the new process commissioning.

Fig. 7 shows a recently modified SAG circuit (after several millions of dollars of capital investment) showing a tremendous variability of the feed tonnage (lower trend; S.D. of 9.7 tph on an average of 131 tph) and bearing pressure—indicating ‘mill load’ (upper trend; S.D. of 24 kPa on an average of 4454 kPa) following ‘commissioning’ of the new equipment and few basic controls. Needless to say, this ‘fundamental and critical control’ affecting the whole mill, was soon switched to ‘manual’ placing onus on the operator to maintain mill throughput while not exceeding any of the equipment constraints! Much of the operators’ time was then consumed with this task.

“In grinding, control of AG/SAG mill circuits is the dominant area. While some systems have emerged which provide a reasonable level of control, there is still much not understood about the dynamic behaviour of these mills, and there is considerable scope for further development.” (McKee, 1999)³

2. Elements necessary for successful Process Control in mineral and metallurgical plants

This section discusses the elements necessary for successful Process Control in mineral and metallurgical plants and what is required to attain operational performance excellence.

Thwaites (1993), Flintoff and Mular (1992) and McKee (1999), as illustrated in Fig. 8, show that successful Process Control is more than the tools—the sensors, PLC/DCS, control software, process information, etc.

It has been the experience of the XPS Process Control Group, that successful Process Control results from a combination of tools (including sensors, PLC/DCS, etc.), knowledge—fundamental process knowledge and control engineering, i.e. people, with the ability to make actions through the support and acceptance of the operations staff/management. Engineering and I/S are also important players in successful Process Control implementation.

2.1. People—control/process knowledge

McKee (1999; Commentary by Sommer, 1992):

- “Many countries lack experts who are trained in Process Control, and who have a good understanding of the process and control engineering expertise.”
- “Process engineers in mineral-processing plants are generally not well trained in Process Control and, except in very large companies, there are usually no process-control engineers on the plant.”

³ Section 2.2.2 discusses a ‘SAG Charge Controller’ (Bartsch, 2006/2007).
This section addresses both of these points.

The XPS Process Control Group’s philosophy is summarised as follows:

a) Employ appropriate number of skilled resources:
   - Having technical ability and training;
   - Championing Process Control and process improvements.

b) Participate and have projects in Operations linked to the Business Unit plans, covering:
   - Operations support, audits, process analysis studies and support of Six Sigma projects.

c) Support capital project design engineering:
   - Ensuring appropriate levels of instrumentation and controls using control strategies based upon an ‘approved’ operating philosophy and standards.

d) Capabilities and services of the Group are primarily:
   - Process design and commissioning;
   - Controls auditing;

Fig. 7. SAG ‘Basic’ feed rate control (early).

Fig. 8. Process Control is more than tools.
• Control loop optimisation;
• Advanced controls;
• Slow process response;
• Off-gas system controls.

The Group maintains an ability to identify and deliver robust Process Control technology and engineering solutions to operations and strategic projects. Solutions implemented are based upon solid control engineering practice and operating experience from throughout Xstrata operations. Enabling, and appropriate technologies, are used through the involvement of engineering specialists who may involve, or work with other outside specialists/consultants/contractors complementing the Group’s skill sets and competencies.

All the current members of the Group are from an Engineering background covering Mineral Processing, Metallurgical, Chemical and Electrical Engineering. Several have Masters’ and some have a PhD in some aspect of control or advanced control. The Group has many years of experience with a diverse and comprehensive background. Academic background covers degrees from the following academic institutions:

- Laval, Québec;
- Malaviya National Institute of Technology (India);
- The University of Manchester (UK) MSc program “Advanced Control and Systems Engineering”;
- McGill, Québec;
- McMaster, Ontario;
- Natal, (South Africa);
- Nottingham (UK);
- Ottawa, Ontario;
- Queens, Ontario;
- Sheffield (UK);
- RSM, Imperial College University, (UK);
- TUNS, Nova Scotia;
- U of T, Toronto, Ontario.

For example (Manchester University website), MSc in Advanced Control and Systems Engineering (Fig. 9):

“Over the past decade our MSc program demonstrated its success in terms of producing high quality graduates that lead to both industrial and academic positions. The program consists of both fundamental theory as well as practical experience through laboratory exercises, computer-based simulation and industrial case studies. Control Engineering is a multi-disciplinary subject, with applications across a wide range of industrial sectors. While an introduction is usually provided during undergraduate engineering programmes, especially in Electrical Engineering, these cannot allow sufficient time to cover modern developments in detail and develop sufficient practical skills. The Control Systems Centre’s MSc programme aims to equip graduates, from a variety of scientific and engineering disciplines, with both the theoretical and the practical skills necessary to apply modern control techniques to a wide range of industrial problems and/or embark on further research. A strong feature of the programme is the dissertation project, which constitutes half of the credit rating and is the means by which students can be introduced to some of the most important topics in modern control.”

Attention has not just been on the XPS Process Control Group capabilities and competencies. For several years now, the XPS Process Control Group has facilitated basic ‘Process Control Training’ generally addressed to all new (Metallurgical) Engineers in Training (EITs), Process Engineers and Instrumentation Technicians. The course involves three day sessions focused on approximately fourteen students per session. This is both necessary as well as ‘good common sense’ in increasing the awareness and importance of Process Control in modern plants. We have seen huge impacts in ‘empowering’ operations, e.g. Falcondo as a result of taking this training. Presently there are considerable opportunities to extend to the ‘new’ Xstrata operations. While this training has actually been given by Lakeside Process Controls (Koehler), similar sessions are given by Top Control (Ruel), metso minerals (Vien, 2006) and more recently, AMIRA (in the P893A Project Extension—‘Training in Process Control”).

P893A Extension (Mujica, Yacher, Coetzer, & Cipriano, 2005) aims to analyse aspects of training in instrumentation, automation systems, Process Control and robotics technologies in copper mining companies. While primarily focused for the South American operations’ (operators), AMIRA would probably be open to extending this training to any interested, paying customer.

There are also specific vendor training programs, such as: Invensys, Emerson, E&H, METSIM, ABB, Perceptive Eng., etc. These are very important to fully realise the benefits of installed control systems and their associated software. Fig. 10 shows excellent Process Control training equipment being integrated to an Emerson DeltaV (DCS) control system at MIT (Madras Institute of Technology, Anna University, India). More such systems are required to introduce Canadian engineering graduates to process control!
Process knowledge comes from projects and work in the plants and piloting facilities. A centralised (XPS Centre) and decentralised (plants) model is practised that allows ongoing connectivity to operations, mentoring, technology transfer, resource time management, benchmarking, and performance management (see Fig. 11). New Engineers are not left on their own, but instead tap into experience and operating examples throughout the Xstrata operating plants. Furthermore, key standards and practised methodologies are communicated and utilised as much as possible. Some of these are discussed in Section 2.2.

2.2. Tools—instruments, systems, technology, etc.

“\[It would appear that less than full advantage has been taken of the advances made in the last two decades in control hardware and software, instrumentation, and control theory.\]” (McKee, 1999; Commentary by Paton, 1993)

The Ontario Plants of Xstrata have specific (discounted) procurement agreements covering instrumentation from Emerson (e.g. Fisher-Rosemount), Siemens, and E&H. Each manufacturer, and associated supplier, provides excellent instrumentation that is significantly better than that supplied to plants in 1993. For example, E&H’s new Memosens pH instrumentation (Tell, 2007) with integrity memory (Fig. 12) can substantially reduce calibration time, is easily interchangeable, can rejuvenate while awaiting service, and can easily be connected to an asset management system—providing a complete service and diagnostic history. Standardising on manufacturers (and associated suppliers) like E&H, Emerson and Siemens, has distinct benefits to Xstrata operations and the XPS Process Control Group. Furthermore, difficult measurement issues, often found in milling and metallurgical plants, can be communicated back to supplier R&D facilities through user groups and forums. ‘Customer Advisory Councils’ are
held by E&H yearly, in three different regions of the country; and recently an international forum was held specifically to address the mining sector.

Other ‘key standards and methodologies’ that are important in applying a common methodology while ensuring a timely implementation:

1. Control and control related systems:
   - Support & exploit installed DCS (generally ABB, Foxboro & Fisher-Rosemount) and Hybrid PLC systems (like Modicon, utilising IEC61131, i.e. Concept—a multi-function programming language);
   - PROFIBUS for Fieldbus;
- ExperTune for optimal loop tuning and PlantTriage for continuous loop monitoring;
- Smith Predictor for single loop time delays;
- Automatic Setpoint Regulation System (ASRI) for Crusher [gap] Controls;
- Connoisseur (Invensys) for (MPC) Model based Control;
- OPC for interfacing different systems.

2. Plant management monitoring (PMIS):
- OSI Pi.

3. On-line failure and fault detection:
- MonitorMV (Perceptive Engineering) for Furnace analysis and on-line fault detection.
- LeakNet (EFA Technologies) for pipeline leak detection.

Some specific examples are discussed below.

2.2.1. Automatic Setpoint Regulation (ASRI)

The Sandvik ASRI Controller for Crushers (shown in Fig. 13) offers an excellent approach to crusher regulatory controls. Easily interfaced through OPC, the unit provides an ‘off the shelf’ system with several control options, the most common being crusher gap control. These units are presently installed at Xstrata’s Kidd, Strathcona and Raglan Mills. The latter is integrated in an important overall automatic grinding circuit control strategy (Bartsch, 2006/2007) where varying the crusher gap setpoint has been necessary for overall circuit control.

2.2.2. SAG charge controller

“In grinding, control of AG/SAG mill circuits is the dominant area.” (McKee, 1999)

“there is still much not understood about the dynamic behaviour of these mills, and there is considerable scope for further development.” (McKee, 1999)

“It often appears that process control systems are expected to do the impossible in having to respond to extreme and unpredictable variations in plant feed conditions (e.g. feed size and hardness to AG/SAG grinding, extreme ore type changes to flotation).” (McKee, 1999)

Fig. 14 illustrates an example of integration of several components of technology in order to achieve SAG mill control. Wipfrag image cameras provide key continuous information regarding the changing feed size distribution as it enters the mill. An ASRI system is incorporated into the controls to allow rapid change in the nature of the recycle materials, through crusher gap control, and cyclone overflow density control is used to manipulate both the cyclone feed density and the circulating load around the subsequent ball mill. Overall these are utilised in a multivariable (MV) charge controller as shown in Fig. 15. Embedded in the control system, power, charge, feed size and assay information are utilised in a
fuzzy controller to control SAG feed rate, and grinding circuit density, crusher gap. Addition of mill speed, when possible, further adds to the controller’s effectiveness. The Concept fuzzy controller is a simple alternative to an Expert System typically used.

2.2.3. Flotation level and froth imaging

“Robust control of flotation circuits remains a major challenge.” (McKee, 1999)

“In an ideal situation, collectors should absorb selectively on the valuable minerals, and depressants should absorb selectively on the unwanted gangue minerals. Unfortunately, this is almost never the case and the right combination of collectors and depressants require the dedicated chemicals; and a lot of fine-tuning in the flotation process.” (Akzo Nobel website)

Flotation is so fundamental to the separation of copper, zinc, nickel and lead sulphides. Therefore it plays a very important part to the Xstrata operations. Optimum flotation performance is reliant on good level control, air sparging and flow control, as well as precise chemical additions. Significant opportunities are found in flotation operations by attention to these fundamental controls. Flotation control has, should have, and will continue to have, a lot of attention from plant metallurgists and control engineers (Thwaites, 1983, 1986; Flintoff & Mular, 1992; Gillis, 2000). It is the process area of significant upgrading of commodity minerals/metals.

Fig. 16 illustrates two different methods that have been used to improve basic flotation level measurement using accurate (and low cost) ultrasonic level sensors. At the (Xstrata Cu) Collahuasi mill, following commissioning, it was necessary to upgrade all of the flotation level measurements to this style of unit—thus improving flotation performance.

Fig. 17 flotation cameras (Metso Minerals, 2004) are now offered by several different suppliers (including, JKTech, metso minerals and MinnovEX). Froth texture, froth velocity and bubble size are some ‘new variables’ available to the control engineer. What is exciting about this technology is the much faster dynamics (typically 1 min or less) that cameras can operate at, as compared to XRF (X-ray fluorescence) technology updating at 10–20 min. Froth velocity is a more direct indicator of mass pull, i.e. recovery, and froth texture and bubble size is a good indicator of acceptable or poor flotation performance. More work is required here before Xstrata operations fully benefit from this ‘recent’ exciting technology. XRF assay information still remains fundamental to flotation optimisation.

Fig. 18 illustrates the flotation level and froth velocity changes during a typical disturbance. The velocity information reveals not only the significance of the level disturbance, but also that the base pull (recovery) is too low! By displaying the velocity signal, this is now immediately evident to the operator!

Metso Minerals (2004) suggest the cascade of froth velocity to the cell level control—as practised at Escondida, and under test at Xstrata’s Strathcona Mill.

2.2.4. On-demand sample automation and points on control structure

Flotation performance is difficult to control because it is integrally tied to the performance of the online sampling systems for the XRF.

Best practise at Xstrata is the use of automation for the sampling system (Thwaites & Løkling, 2002). As shown in Fig. 19, primary samples are only run when the analyser needs them. They are then automatically shutdown and flushed with
water. Lower maintenance and higher on-line times result. This is necessary for advanced, robust controls of the flotation process. Robust and accurate assays allow better flotation control, often in a layered approach as shown in Fig. 20 (Gillis, 2000). This allows for a compromised control when key measurements become unavailable. Layered control also allows for the implementation of additional controls at a later date.

2.2.5. Model predictive control (MPC)

MPC applied to Xstrata processes was addressed by Sandoz (2006). Included were:

- Roasters (Connoisseur, e.g. Kidd Zinc—1993);
- Flotation Process (G2/Generalised Predictive Control—GPC)—originally implemented by Noranda in 1999;
- Flotation Level Control (FloatStar, Mintek—Collahuasi, 2004);

Fig. 16. Flotation level controls (Thwaites).

Fig. 17. Froth camera imaging technology.
There are many references covering the applicability of MPC. Recently, Gordon (2007), in the 11th and final article in a Process Control series (topic: Select the Best Process Control), focussed his article on ‘Choosing between PID and model predictive control depends on understanding your process and all its interactions.’

“MPC controllers do a much better job at controlling around constraints. Because MPC can predict future behaviour, collisions, with constraints can be anticipated. In response, control moves can be applied that will bring the process to rest against the constraint limits.”
The XPS Process Control Group obtains process identification information from tools (like Invensys’ Connoisseur) that allow PRBS (pseudo random binary sequence) tests on the process. These more complex tests, would follow the simple initial step tests used for identifying basic process dynamics.

However successful and beneficial, these systems will not be robust in the long run unless there is an appropriate and knowledgeable resource capable of maintaining and supporting them.

2.2.6. Failure, fault detection and PCA/PLS

"Similarly, the value of process control must be recognized. In the 50 year time span being reviewed in this (JOM) paper,
process control has emerged from its infancy in instrumentation—sensor, alarms, level controls, etc., to the much higher levels of operational prediction and performance optimization. An example is the use of multivariate analysis techniques in smelters to alert operators when furnace run-out conditions are being approached.” (King, 2007)

While online systems like EFA Technologies Inc. 'LeakNet' fault (leak) detection system have been available for oil and slurry pipelines for several years, similar applications to the metallurgical industry’s key process equipment are very limited. One such system (Fig. 21) has been developed (Thwaites et al., 2004; Nelson & Hyde, 2007).

“Extending the campaign life of the Mitsubishi furnaces at Xstrata Copper’s Kidd Metallurgical Division Copper Smelter has been a major focus of attention for many years. One aspect of this effort is real time monitoring to detect abnormal conditions and safely shut the furnaces down before significant damage occurs. Traditional real time methods of monitoring the integrity of refractory furnaces containing molten metal include alarms on individual temperatures of the refractory or cooling water. Integrity monitoring systems that look at many different signals and alarm only changes in the relationships between the signals have been implemented on the smelting and converting furnaces. The systems are based on principle components analysis (PCA) models and implemented with the MonitorMV software package. These provide much more sensitive and selective alarms so that changes in integrity are alarmed well in advance of any event. At a critical alarm level, the converting furnace is set to automatically shut down so that operating personnel can review the situation.” (Nelson & Hyde, 2007)

The application was developed in concert with Perceptive Engineering, UK (Sandoz, 2003) and is described in detail in the Canadian Patent no. 2,469,975 (Thwaites et al., 2004).

2.3. Actions—support of management, technology transfer, etc.

“Enthusiastic support of management for process control” (McKee, 1999)

“The elements which make up a control system have always required skilled support and they always will. Where this support exists for instrumentation, control hardware and software and process control knowledge, the systems are invariably successful. Whether the systems are relatively simple or quite complex, it must be recognized that process control is not a simple technology. Ultimately, the necessary level of management support and commitment is essential. It is remarkable how often large investments in control are made in the clear knowledge that the necessary support is unlikely to be available. Under these circumstances, dissatisfaction with the eventual outcome is guaranteed.” (McKee, 1999)

As shown in Fig. 8 (Thwaites, 1993) the Operations support is a ‘pillar’ for good Process Control. After all, they are the client who knows best what the process and plant economics are, and the areas requiring focus for maximum benefit. They should understand enough control to identify what is operating in their plant and what the potential of the systems are. The right key performance indicators (KPIs) can be very beneficial here.

Fig. 22. XPS process support: pilot plants.
3. XPS Process Control philosophy summary

Two of the four business groups at the Xstrata Process Support Centre, the Process Mineralogy Group and the Extractive Metallurgy Group, operate pilot facilities (Fig. 22) that cover milling and flotation processes, as well as hydrometallurgical and pyrometallurgical processes. These are excellent facilities to utilise ‘state of the art’ instrumentation, like Coriolis meters, as well as fieldbus technology (e.g. PROFIBUS), thin client MMI systems together with integrated controls (mostly with Concept—a IEC61131 programming language).

The philosophy and practise of XPS piloting is to engineer to an equivalent or higher standard as the operation plants, thereby obtaining key controls knowledge, by obtaining excellent process data. Often these data are used in detailed engineering studies.

Fig. 23 shows the application of (Emerson) Coriolis meters to the pumping station of an oil pipeline. While this is a ‘simple process’ it summarises very well key steps in the improvement of the process of pumping oil over many kilometres. Prior to the Group’s involvement there only existed a pressure measurement at the inlet and on at the outlet, both were monitored by a Pi PMIS system.

Additional instrumentation added included: flow measurement (Coriolis) at the inlet and outlet, additional pressure measurements along the pipeline, and tank levels. All measurements were then continuously monitored and captured by the Pi PMIS historian including: pressure/flow difference calculations, and pump amps/volts measurement. Robust communications, plus pressure controllers on the inlet and outlet, were installed and commissioned. Finally a leak detection system (EFA Technologies Inc, 2002) was commissioned using the added process data. Ultimately, auto shutoff valves together with a segmentation strategy, bring this process to one of ‘state of the art’—mitigating operational risk.

Fig. 24 summarises the XPS Process Control Group’s philosophy in applying common methodologies, tools, approaches, synergies and technical exchanges to mills, pyrometallurgical, hydrometallurgical plants, and plants of the future (pilot plants). This applies to copper, zinc, nickel operations as well as acid plants, petroleum and power plants owned and operated by Xstrata.

4. The ‘near term’ outlook

Instrumentation is so much better than it was 25 years ago and procurement agreements with key, major suppliers allows the latest technology into the plants where they are ultimately proven for both accuracy and robustness. Utilisation of ‘asset management’ systems (like E&H’s FieldCare) will help to ensure instrumentation is performing appropriately. But this is also where other tools, like PlantTriage (ExperTune Inc.) and
online PCA/PLS models (MonitorMV, Perceptive Engineering) can play an important part—quickly identifying and reporting failed instrumentation to mitigate costly productivity losses and expensive equipment problems/failures. Well tuned, adaptive—where necessary, control loops operating in auto are essential for Operational Performance Excellence. While most are still PID and cascade PID, there are excellent MPC (model predictive control) and MV (multivariable) fuzzy controllers operating robustly.

Fig. 25 (Sandoz, 2003) illustrates integrated condition monitoring and advanced Process Control. Their tools (e.g. MonitorMV and ControlMV) are presently running online doing classification, early warning conditioning monitoring, with soft sensors integrated to plant control systems.

Beyond the ‘tools and systems’ new improved mineral beneficiation processes, are gaining a worldwide acceptance (at an increasingly rapid pace), like Xstrata Technology’s IsaMill (Pease, 2007) and ISASMELT (Bakker & Arthur, 2007). These provide interesting opportunities to further Process Control and PCA/PLS analysis and on-line systems. It is indeed an exciting time to be working in the minerals and metallurgical control industry.

5. Conclusions

Konigsman (1992): "Process control is now an essential part of any concentrator operation. It provides a proven vehicle for improving operation economics by increasing revenues and reducing costs. A substantial number of Canada’s mineral processing plants have incorporated this technology, and most have realized impressive returns on investment. The question one must ask is whether we are tapping the full potential of this technology. It is the opinion of the MITEC Mineral Processing Technical Advisory Committee (TAC) that the answer to this question is 'No!'"

"Similarly, the value of process control must be recognized. In the 30 year time span being reviewed in this paper, process control has emerged from its infancy in instrumentation—sensor, alarms, level controls, etc., to the much higher levels of operational prediction and performance optimization." (King, 2007, ‘Is the Best Yet to Come?’)

Plant automation is often seen as the project deliverable, when what is really required is plant control. There are many approaches, instrumentation, and multiple control systems, together with numerous ‘advanced control’ packages to select from. Process Control has been presented here (and previously by Flintoff & Mular, 1992) as more than just tools. Successful plant implementation is reliant on these together with process knowledge, a solid control engineering background/experience, and the operations team willing to act/implement/support the implementations. Together robust solutions can be realised, minimising process variation and optimising process performance. This will result in an easier, efficient and safer process to operate (Lovett et al., 2007). Furthermore, at present metal
prices, financial gains can be substantial (on a project to project basis). The SAG charge controller, referenced in Section 2.2.2, was recently evaluated in contributing to a 5–8 tph (3.6–5.5%) mill production gain—value to Xstrata Nickel at Can.$ 20–30 million per year!

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Strathcona Mill,
Raglan Mill,
Collahuasi Mill,
Kidd Site,
Altonorte Smelter,
Mt. Isa Cu Smelter,
Pilot Plant Activities,
Sudbury Ni Smelter,
Nikkelverk Refinery,
Falcondo Site,
Brunswick Smelter,
Horne Smelter,
CCR Refinery.

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‘Corporate responsibilities’ associated with Process Control. In 1996 Philip left Timmins, with his family, to continue this work at the Nikkelverk Refinery in Kristiansand, Southern Norway. Focus shifted from copper and zinc Process Control and optimisation to nickel, copper and cobalt. Philip worked at the refinery for 3 years, also learning Norwegian, before returning to Canada, settling in Sudbury in 1999. In 1997 a ‘new’ technology centre, located next to the Falconbridge Nickel Smelter, was completed. On returning to Canada in 1999, Philip has led, and continues to lead, the Process Control Group, a multidisciplinary team, from this ‘state-of-the-art’ centre. The ‘Group’ works in the Company’s operating plants and pilot facilities around the world—ensuring metallurgical processes are running efficiently, utilising instrumentation and control.