Minerals Engineering 79 (2015) 139–142

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Benefits of process control systems in mineral processing grinding circuits

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ARTICLE INFO

Article history:
Received 21 March 2015
Revised 2 June 2015
Accepted 3 June 2015
Available online 11 June 2015

Keywords:
Process control
Mineral processing
Quantitative benefits
Business case

ABSTRACT

In 2009, the survey of Wei and Craig reported qualitatively on the benefits of process control systems in grinding and flotation. The present review of about twenty milling operations reports quantitatively on these benefits. Expert systems, model predictive controller, and fuzzy logic control systems, to name only the most used in the mining industry, have delivered superior operational performance (1–16% gain in ore throughput, at least 40% reduction in mill load variability, up to 1% in metal recovery in flotation) and reduced operating costs (15% reduction in grinding media consumption 52% reduction of the cyclone pressure variability).

1. Introduction

This article focuses on quantifying the benefits of process control systems in the mineral processing industry. The benefits sought in the mineral processing industry are the same sought in other commodity industry, namely throughput gain, process stability, energy consumption reduction, and increased yield. A survey by Bauer and Craig (2007) of 66 respondents from diverse commodity industries, including mineral processing, reported on the preferred types of control systems and hinted to some gains in throughput of between three and ten percent. Two years later, Wei and Craig (2009) narrowed their survey to mineral processors only, of which 68 responded, the majority of them from the precious metals and base metals industries in Africa and Europe. Of all respondents, 35% used single-stage milling in closed circuit, 30% used two-stage milling in open and closed circuits, 22% used two-stage milling in closed circuits, and 15% used other circuit configurations. The respondents used one or more control strategies, PID control being the most common, multivariable control and expert system-based control being on par, following distantly by fuzzy logic control, neural networks, and others (adaptive/self-tuning control, model predictive control, linear programming, statistical process control, dead-time compensation control, constraint control). Eighty-nine per cent of respondents used on/off trials to demonstrate the benefits of the control system. Greater process stability was common amongst 71% of respondents, throughput gain by 54% of them, energy consumption reduction by 50%, increase yield of the valuable products by 43%, operating labour reduction by 30%, downtime reduction by 21%, and better plant safety by 16%.

The business case for a control system needs to consider the costs of control hardware, control software, consultant labour, production loss due to installation downtime, and hardware/software maintenance. Against these costs are the benefits of lower operating costs and higher metal production. Metal production is given by the product of head grade, throughput and recovery (metal produced = grade × throughput × recovery). Assuming grade to be constant, a key objective of control systems in milling operations is to establish the ore throughput and recovery relationship, shown indirectly in Fig. 1 as ore throughput and metal production. For some ores, increasing throughput outweighs the possible decrease in recovery caused by a coarser grind and lower grain liberation. For others, there exists a throughput "sweet spot" above which recovery drops so sharply that it defeats entirely the throughput gain. Controlling throughput and grind size with adjustment of ore feed rate to the mill and water flow rate to sumps and mills is the foundation of grinding control system.

Whereas Wei and Craig (2009) identified the users of grinding control systems and cited the qualitative benefits of such systems, the present article goes one step further, compiling quantitative data for such benefits. It is the first time that a compilation of this sort is made. Metallurgists and process engineers interested in implementing control systems will find much value in this compilation, having now readily available quantitative evidence from many different sources to build a business case in support of continuous improvement initiative for grinding systems.

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http://dx.doi.org/10.1016/j.mineng.2015.06.006
0892-6875/

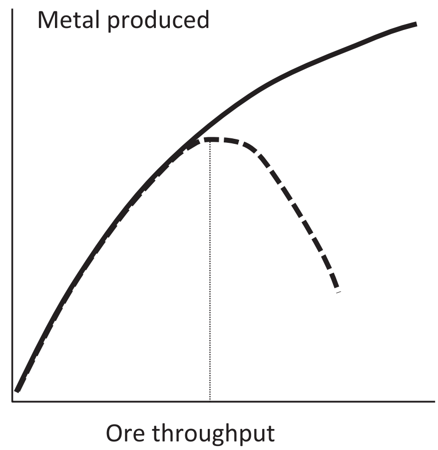

Fig. 1. Possible existence of an optimum throughput above which metal production could decline as a result of coarser grind, lower liberation, and thus lower metal recovery.

2. Methodology

This study was realized independently of the survey of Wei and Craig (2009). It pulled information from eighteen published sources, which included conference proceedings, referred journal articles, and vendor brochures. No operations survey was conducted.

The published literature contains many articles about grinding control systems, many of a theoretical nature with no reference to any operations, and others presenting simulations that refer to certain operations. Even though such articles may cite performance benefits, they are not the subject of this study, concerned only with actual operational data.

3. Results and discussion

Gold, platinum, copper, nickel, zinc, and iron operations from across North America, South America, Africa, and Australia, were examined. There were zero rod mill operations, three ball mill operations, nine SAG mill operations, three rod and ball mill operations, zero rod and SAG mill operations, and seven ball and SAG mill operations.

Table 1 summarizes the information collected as a function of the type of control system and the commercial control system used, the objective(s) set out for the control system, the manipulated and controlled variables, and a suite of quantitative metrics, including mill load, grinding media wear, power consumption, ore throughput, cyclone performance, recovery benefit, labour, downtime and utilization, and safety.

3.1. Types of control systems

The types of control system used were: twelve operations using expert systems, six using model predictive controllers (MPC) (no mention whether linear or non-linear), five using fuzzy logic, and occasional applications of multivariate controllers and other systems (PID control, adaptive/self-tuning control, neural network-based control, linear programming, statistical process control, dead-time compensation control, and constraint control).

Emerson Delta V MPC, ABB Linkman Expert Optimizer, Invensys Connoisseur, Honeywell Profit Suite, Gensym G2, Prediktor, Metso Adaptive Predictive Model, and Metso OCS process control software are common commercial control packages (Thwaites, 2009). The dominance of the expert system is reinforced by the claim of White et al. (2004) citing that the former Minnovex (now SGS) installed fifteen expert crusher control systems from 1995 to 2006. SGS Minnovex competition is Metso OCS. Mintek takes up a large share of the market for MPCs. Mintek MillStar has been implemented on many circuit configurations, including platinum group metals and gold in South Africa, nickel in Zimbabwe, Botswana and Australia, silver, lead and zinc in Mexico, gold and copper in Brazil, and copper in Poland.

Whilst this study does not discuss the fundamentals of control systems, it is worth mentioning some key differences between the two most commonly used systems: expert system vs MPC. An expert system uses a model of the operators; MPC uses a mathematical model of the system (Carter, 2010). An expert system is algebraic and rules-based; MPC is algorithm-based and predictive. Expert systems have an optimized supervisory control of mineral processes. MPC track setpoints well, anticipate and reduce disturbances, and can be used for optimization.

3.2. Benefits

Amongst the references consulted, mill operations implemented control systems to achieve throughput gains (thirteen instances reporting), increased recovery via grind size control (nine instances), lesser variability in different areas of the circuit (six instances), greater control of the mill load (four instances), and no grind out (three instances). No operations reported testing more than one control systems in their trials.

The most often cited benefit was an increase in throughput, followed by a reduction of the throughput variability, a reduction of the mill load variability, a reduction in power consumption, a target size achieved, a tightening of the mill feed size distribution, and a recovery gain. This analysis of the benefits confirms the previous survey findings of Wei and Craig (2009) reporting most often process stability improvement, throughput increase, energy consumption reduction, and increased metal production.

Quantitative data for most of these benefits are given in the next sub-sections.

3.2.1. Throughput

Throughput gain is the most often cited benefit of process control systems, followed by lesser throughput variability. Fig. 2 shows a wide range of throughput gains for each type of control systems. The throughput gain data for expert systems is supported by Edwards et al. (2002) who quoted four authors having previously reported “typical” throughput gain of between +4% and +8% with expert systems. Of those publications consulted, none reported a loss in throughput; it is construed that operations which might have experienced a throughput loss did not publish results. The vertical bars in Fig. 2 represent the average of the range. Five to seven percent throughput gain is the average of these types of control system. No system seems to outperform another.

The majority of operations using model predictive controllers also commented on the significant reduction in the variability of throughput, by a factor between 22% and 92%. Operations using other control systems did not make such frequent mention of a reduction in throughput variability.

3.2.2. Recovery

Table 1 shows significantly fewer references quoting a gain in recovery. From −0.7% to +1% is the range reported. When using a fuzzy logic controller, the Xstrata Nickel Raglan operation reported a 0.7% loss in recovery, but such loss was more than offset by the 3–6% increase in throughput. The operation produced more nickel as a whole, but that came at the price of losing to tailings 0.7% of every nickel tonne fed, that would otherwise have been recoverable under more optimum conditions.