Poly-Stream Comminution Circuits

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Abstract. Comminution and classification circuits consume significant amounts of energy. Some estimates show that comminution processes accounts for around 40 % of the total energy consumed in mining operations and 1.5-1.8 % of the total national energy consumption in mining intensive countries such as South Africa, Australia and Canada (Tromans, 2008). Apart from recent market fluctuations the global trend is that the demand for metals and minerals is increasing (Norgate and Haque, 2010). At the same time the ore competence generally increases as material is mined at greater depths and the grade is usually lower. The consequence is that increased amounts of raw material need to be processed in larger and larger comminution devices. The task of reducing the energy consumption in this context seems daunting.

The conventional comminution circuit is usually based on a crushing and screening process followed by a tumbling milling process. HPGR machines and other new devices have also become more common during the last 20 years. Independent of what type on units that are used in the circuits the global trend is that larger and larger comminution devices are manufactured and installed.

With this outlook as a foundation we propose an alternative mindset to think about circuits; poly-stream comminution circuits. A general trend in product development is that technologies transform from mono-systems to poly-systems. In this paper the concept is described and exemplified in a case study including a comparison with a conventional SABC circuit. In poly-stream circuits the material streams after one or several parallel primary crushing stages are split into 5-20 streams by using ore sorting and classification units. Each stream handles a proportional throughput capacity and the material passes through a dedicated set of smaller comminution and classification modular units with settings optimized to target the specific properties of the material in each stream.

The results of this conceptual case study suggests that smaller, instead of larger, comminution and classification units open up for modularization, higher theoretical operational availability, better plant flexibility and expansion potential. Lower mass flow streams enable the use of ore sorting with separate treatment and early rejection of gangue. It is generally also easier to achieve higher energy efficiency performance for smaller comminution, classification and separation units.

There are a number of apparent challenges and problems associated with the concept. It requires new solutions for stream re-routing, sensor technology, advance control systems and advanced maintenance management systems to name a few. However, the consequent conclusion of this hypothetical concept is that perhaps the focus of research and development efforts should target material handling, sensor technology and comminution unit modularization in order to meet the challenges of future comminution circuits.

Keywords: Comminution, Energy efficiency, Pre-concentration, Ore Sorting, Circuit Design

INTRODUCTION

The comminution of ore materials in crushing and milling processes contributes to a substantial part of the total energy used by the mining industry. The exact proportion is naturally unique to each mining operation, however, Lessard et al have reported about 44% of energy can be attributed to the comminution process in relation to the total energy spent in a particular mining process. Tromans have reported on energy statistics from several countries that suggest similar findings. In a study by BSC Inc. for the U.S. Department of Energy (2002) estimations on the energy use by each equipment type for a typical iron ore and copper process are presented. The results showed that for the iron ore case study the comminution machines contributed to 12 % of the total energy from the mining process to finished pellets. The iron ore case study process was a three stage crushing, ball mill and rod mill circuit. In the copper ore case study the results suggested that 75 % was attributed to comminution processes. The circuit was a conventional SABC circuit and the major contributing units where the SAG and ball mills.

Many mining companies are struggling at the moment to keep their profit margins due to a strained market and operational cost problems. The persistent trend of decreasing grades has forced minerals processing operations to handle increased tonnages. This is commonly dealt with by installing increasingly larger AG/SAG mills such as e.g. the 22.5MW SAG mill (Ø11.6, L13.7m) at Aitik Boliden or the 28 MW SAG mill (Ø12.8m) for the Conga project by Newmont Mining Corporation in Peru. These kinds of mills are of course able to process very large throughputs and the circuit flow sheets are non-complex.

The trend of decreasing grade qualities and increased ore competence (Mudd, 2007; Northey et al., 2014; Prior et al., 2012) will most likely not turn. So what is the best development strategy for comminution circuits of the future? It is most likely possible in an engineering perspective to design and build even larger mill than the currently largest ones. However, one has to ask if this is really a sustainable route that can fulfill the objectives of lowering the costs and reducing energy and greenhouse gas emissions. The prospect of achieving significant energy efficiency improvements for conventional tumbling mill circuits by e.g. manipulating the operating conditions are very poor. Morrell (2008) concluded in his study of 65 different circuit designs that, within the limits of the precision of the equations, an increase of only 7% other than that caused by pebble recycle crushers. As a final remark Morrell points towards the use of multi-stage crushing and HPGRs as a means of achieving energy efficiency improvements.

In this paper we discuss an alternative route for future development of comminution processes, a concept based on multiple streams; poly-stream comminution. Before the concept is discussed in more detail we will elaborate on the rationale based on generic technological trends defined and formulated in the TRIZ methodology (Altshuller, 1988; Savransky, 2000).

Technological trends

When analyzing the technological evolution of products and systems they commonly follow specific patterns. Savransky (2000) elaborates on this and defines three groups of trends or corollaries. These trends are described below with some reformulations, subtractions and additions.

Group I

Multiplication: transition from a mono-system to a bi-system or to a poly-system.

Trimming: reduced number of subsystems for neutral and auxiliary functions.

Poly-functionality: increased quantity of value adding functions of a technique by adding new subsystems.

Aggregation: achieving several functions within or by one subsystem.

Group II

Dehumanization: exclude people from conducting noncreative work through mechanization, automation and computerization.

Minimization: achieve the optimal dimension, weight, and/or energy consumption of subsystems.

New materials: substitute current material with a new that holds advantageous properties.

Group III

Encapsulation: configuring replaceable subsystems into more easily manageable cassette or cartridge.

Modularity: configuration of interfaces enabling modules as subsystem building blocks.

Standardization: unification of dimensions, shapes and other properties of subsystems.

Reuse: using subsystems that have already been previously implemented as subsystems in a new system or process.

One of these patterns is characterized by the transition from a mono- to a poly-system (Savransky, 2000). A technology that has achieved its limit may continue at the level of a super-system. New characteristics and parameters can be achieved by joining sub-systems of other techniques into the super-system.

Altshuller (1988) elaborates on this issue in a general manner in what he defines as 5th standard for the solution of inventive problems:

"Standard 5. It is necessary to increase the technical specifications of a system (mass, dimensions, speed, etc.) and this comes up against obstacles of fundamental importance a (ban imposed by natural law, the absence of the necessary substances, materials, power in the present state of technology, etc.), the system must be introduced as a subsystem into another more complex system. The development of the original system ceases and its place is taken by a more intensive development of the more complex system. "

The knowledge on technology trends hence suggest that the comminution and classification process as a system must be transformed to a subsystem in a super-system where a set of new subsystems are introduced, increasing the complexity, in order to reach a new level of performance.

In the case of minerals processing and comminution, a relatively newly introduced such sub-system is the technology of sensor based ore sorting (SBS). Other technologies waiting to be implemented are different kinds of pre-weakening techniques (e.g. SELFRAG).

Opportunities to explore

In order to meet the challenge of sustainability there are a set of characteristics that needs to be explored. In the case of comminution and classification three of them are listed below:

- Rejection of material identified as non-profitable to process as early as possible.
- Use smaller comminution and classification devices with higher energy efficiency
- Enable implementation of new sensor technology

POLY-STREAM PROCESSING

Schönert has shown that the slow compression of single particles is the most energy efficient mode of breakage (Schönert, 1972, 1979). The optimal comminution system would apply the minimum energy required to sufficiently break each individual rock particle based on its properties, while not breaking it too much. This is very difficult to achieve when trying to process a stream of many particles simultaneously, hence everything is commonly treated the same way. The optimality is constrained by the fact that in most of today's comminution plants, all material passes through large machines that process everything under the same conditions. In order to unlock the next level of optimality a higher information fidelity level regarding the particle stream needs to be utilized. This requires online characterization, separation and routing technology prior to reaching the comminution units.

The elementary basis of this concept is to split streams on dedicated routes and use several smaller processing units. As an exercise a simple example has been developed in order to evaluate the approximate potential gain in terms of energy demand.

In FIGURE 1 the example circuit is presented schematically. A set of generic symbols have been developed to represent classification, comminution and routing units. This has been done in order to be able to draw a circuit without specifying what type of unit that should be placed on every position.

The rationale of the circuit is to first have an initial size reduction step. Secondly the stream is classified into three different size streams, a fine, medium and coarse. The fine stream is comminuted and classified. The medium stream is sorted, comminuted and classified in a series of steps. The coarse stream can either be directly rejected due to the common case with lower grade in the coarse stream or it may be processed further. The circuit has been configured in order to have a minimum of recirculation load in order to simplify control.

For each stream the approximate feed and product particle size distribution have been estimated. A mass balance have been performed by estimating the classification, comminution and sorting performance of each unit. The feed rate is 2000 tph fresh feed with a top size of 200 mm. Since the comminution unit type is unknown at this stage a simplified energy estimation has been applied based on the relationship between reduction ratio and specific energy requirement. The relationship is based on data presented by Fuerstenau (Fuerstenau and Abouzeid, 2002) on the energy requirement for Single-Particle Roll mill and ball mill as a function of reduction ratio for a quartz material. This is a very crude measure however it allows for a calculation on a scenario where the comminution devices are highly efficient. The ore sorters are estimated to reject 40 % to the waste stream. The last comminution step is estimated to perform as e.g. a stirred mill at 6 kWh/t. When summarizing the total average specific energy the estimation is between 7-10 kWh/t with an estimated rejection between 31 and 44 % depending if processing the coarse material stream.

The poly-stream example is compared against a conventional SABC circuit as shown in FIGURE 2. The specific energies for the SAG and Ball mills have been estimated to 10 kWh/t and 12 kWh/t respectively and for the pebble crusher 0.9 kWh/t. If also considering some classification energy the total average specific energy is calculated to around 30-31 kWh/t.

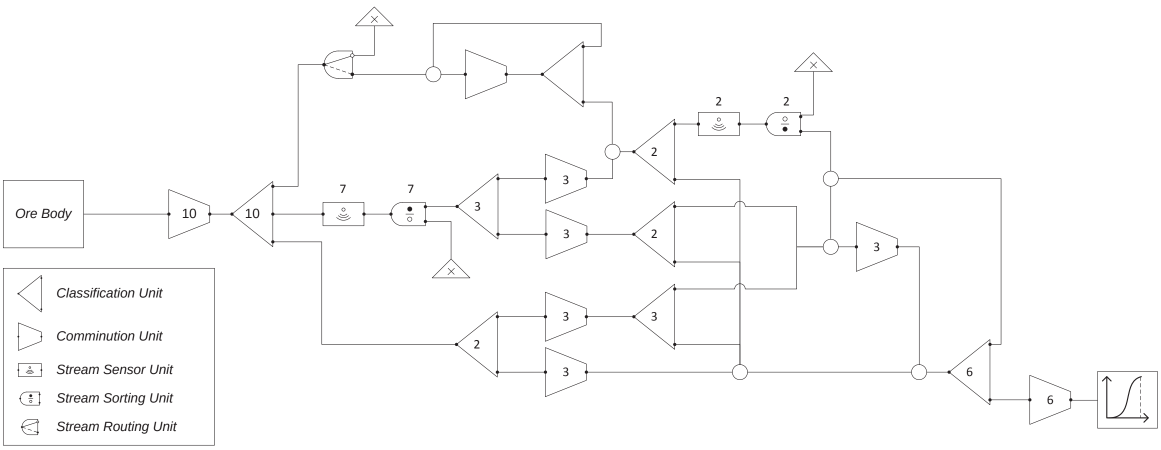

FIGURE 1. Poly-stream example circuit (2000 tph). The numbers in each unit corresponds to the number of parallel units at that position.

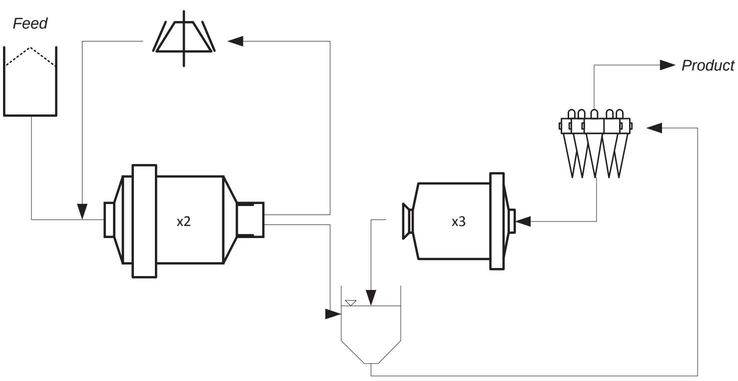

FIGURE 2. SABC (SAG-Ball-Mill-Crusher) example circuit

The calculation exercise performed is very simplified in many different aspects. However the results suggest a potential energy reduction by 70-75 %. Even though this is not a viable case comparison the simple model displays significant effects even if applying a high tolerance in e.g. comminution unit specific energies. The results should of course be interpreted with caution until more sophisticated dynamic modelling and simulations have been performed.

DISCUSSION

The transformation to a poly-stream process with smaller units opens up for a set of opportunities and challenges. First of all it should be mentioned that no Opex or Capex calculations have been performed hence it is difficult to draw any conclusions regarding cost. However, since this circuit may require infrastructure and units that are currently not available such calculation may not be viable anyway at this point.

Opportunities

Downtime and Maintenance

Single stream processes commonly suffer from a relatively high ratio of downtime due to the inherent vulnerability. If one process unit experience either a planned or unplanned stop it will influence the rest of the process. The immediate remedy is achieved by using stockpiles and bins which will provide buffer time. However, these stops will influence the overall process efficiency due to dynamic effects reducing the total production rate (Asbjörnsson, 2013). Planned and unplanned maintenance may be performed without the use of large bins and stockpiles.

A poly-stream circuit has the capability of targeting these issues more effectively. If one of e.g. ten streams are down due to a planned or unplanned stop the remaining capacity is still 90 % and only 10% of the throughput is lost. For planned maintenance it would be possible to keep a standby eleventh redundancy stream in order to always retain the installed capacity. With this strategy, it may be possible to design a circuit that has a theoretical availability of near 100%.

Modularity

Each processing unit will be comparatively smaller than e.g. the large crushers and mills used today. This opens up a wide range of possibilities for OEM equipment suppliers. If designing a comminution unit as a modular cartridge that can quickly be removed and replaced from its position very low stream downtime can be achieved. The small size also opens up for shipping to the supplier for, major maintenance issues upgrading or end of life reclaim of materials and parts according to product lifecycle management principles. These solutions are already in place for several of the HPGR suppliers.

If the interfaces are standardized the comminution devices can be designed as cartridges that can quickly be replaced by either the same type of unit or another type. This would allow for truly flexible circuits.

Expansion

If the poly-stream infrastructure is in place it is easier to expand or contract the circuit by adding or removing units. The parallelization allows for easier integration of an additional unit without redesigning the whole circuit.

Innovation Accelerator

Due to the lower throughput capacity requirement and physical footprint it would be easier to implement and test new innovative equipment such as pre-weakening-, comminution-, separation-, classification- and characterization units.

Challenges

The number of units in the two circuits are increasing from 13 in the SABC case to 78 in the poly-stream case which means the process complexity have increased. The control system would need to process more data and make intelligent decisions regarding e.g. waste rejection.

The main challenge is probably the materials handling and particle stream routing. The design requires multiple splitting points and stream merging points.

CONCLUSIONS

A concept based on poly-stream processing have been formulated and discussed. The potential gains and challenges with the concept have been discussed. This work suggest that the main challenge in developing and applying the concept may be related to the particle transport problem, not the comminution in itself. The inherent issue with multiple streams and how the material is going to be efficiently transported and routed is a great challenge. The complexity of the circuit and the control system would increase together with the amount of information that would need to be continuously processed. Hence, if this is a viable route for the future, the main concerns with overcoming the challenges leading to sustainable comminution may be related to circuit infrastructure, company culture and competence.

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