

Achieving SAG Mill Design Production at Start-Up Using Best Practices – Fact or Fiction

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Abstract

The goal of this address is to review best practices in grinding circuit design, the expectations of clients who build a new plant, the results achieved during recent start-ups, and from this to conclude whether starting up at design tonnage in a SAG mill can be a fact or just wishful thinking on the part of the engineers who design the plant using SAG technology.

Autogenous mills were introduced into the iron ore mining industry in the 1950's to eliminate fine crushing, simplify grinding operations, save capital dollars, reduce operating costs and move the industry forward by capitalizing on the advantages of ore grinding itself. This worked so well that the concept was expanded to include base metals and gold ore. Steel was added to the AG mills to compensate for the lighter host rock that carried the metal values, and mill shells and motors were built to be more robust to deliver the required energy and sustain the additional forces required for semi-autogenous grinding. Dealing with ore hardness variability then became the challenge and new technologies were introduced to measure this variability in a cost effective way.

Questions have been raised because of failures to achieve design tonnage in a reasonable time period, using selected comminution equipment, and whether SAG technology is even capable to meet design criteria on start-up. Other technologies have been tried to avoid SAG milling problems, only to find a new suite of challenges which also are costly to deal with, both from capital and operating cost perspectives.

This paper will show that by using best practices, design tonnage can be achieved in SAG milling circuits at start-up with no added capital being required, and that SAG technology is mature enough to be trusted to deliver the throughput tonnage and revenue planned starting from day 1 after start-up.

Introduction

Recent new plant SAG mill start-ups in Canada have shown that achieving design tonnage from day one happens in some cases but not in others. The magnitude of the shortfalls at three large Canadian plants suggests that there are issues related to building new plants that must be addressed in order to prevent this from ever happening again.

The waste associated with a failed start-up is enormous. The main factors involved are:

1. If the SAG mill is too small, capital revisions will be required. Either pre-crushing, pebble crushing or both may be required. Operating costs will also be higher due to higher steel load required and/or higher mill speed which can be inefficient by comparison with normal practice.
2. If the tonnage achieved is a low percentage of design t/h, then revenue will fall short by that amount, and profits will be dramatically reduced or in some cases eliminated, depending on the metal price and the economic conditions at the time of start-up.
3. Demonstration that SAG technology is inferior will be falsely concluded. Future plants will be designed using other or modified processes and the erosion of good SAG milling technique will be continued, reducing the profitability for every new project which could benefit from SAG technology when properly used.

Whose problem is this? How can these things happen? What are the issues involved?

1. An industry wide problem exists which can be solved by correctly sizing the grinding mills before purchasing them, and by setting global standards for designing new SAG comminution plants following those standards or guidelines. The concept of expecting a long tonnage ramp up period is not necessary and should be replaced by the expectation and matching design to produce design tonnage from day one. This paper will explain why this is important and how to do it.
2. This situation is a problem for the operators who cannot achieve design production, for the owners who have taken responsibility for the project, and for the financiers and shareholders who put up the money to build the plant. If the owner used company money then he/she properly reaps the consequence of the financial shortfall because it was the owner's responsibility to hire a knowledgeable comminution design firm. But if it is investor's money that is used, an additional level of accountability needs to be introduced to ensure that the expected return of capital is possible. If this change isn't made immediately, investors will become wary of investing in a plant using a SAG mill.
3. The issues involved here are technical, financial and ethical. The procedure and requirements to achieve a proper design have been published, notably at SAG 2011, (Meadows, Scinto and Starkey). If these design protocols have not been followed and two reliable methods have not been used by experienced engineers to size the grinding mills, then the consequences rest on the owner for allowing this to happen. Clients always want to have their plants built quickly, but not so quickly that final design work is not completed. Shareholders should not have to pay for mistakes in mill purchase caused by a client buying too small a mill from a willing vendor.

Best Practices

Today, there is variance in opinion regarding what constitutes best practices for SAG mill circuit designs. It is reasonable to say that to qualify as 'best practices' a new SAG mill circuit should start up at design tonnage and produce the design product sizes in each stage. There are recent start-up examples where this has been done, so this goal is achievable.

However there are secondary forces at play: the cost of doing the design work and the time to get it done. Spending lots of money is not a guarantee that the design will be correct. It can be said with confidence that the money must be wisely spent on accurate test work suitable for greenfield project development. But testing is not everything, process design counts too.

The training courses offered at this conference showed that designing the comminution equipment using geometallurgical testing is a good possibility. However, the author can assure you that design and geometallurgy are quite different exercises in scope, in elapsed time, and in cost. Geometallurgy is an excellent way to forecast and control tonnage fluctuations in a process due to ore variability, but in most cases is not required for design because many more samples are required, the cost is much higher, and the time to complete the work can be unacceptable, especially if there is a line up queue for new SAG mills at the chosen mill manufacturer's facility. That is not the case today but 5 years ago queues were common.

When gathering ore hardness variability information for design, it is prudent to use a hardness test that is suitable for the samples selected and to choose the most accurate test available. Some tests are best suited to point samples while other tests are excellent for measuring the hardness of composites or point samples. Other methods are limited by ore hardness or core diameter. It is best to use a test method that has no restrictions.

It has been shown that when kWh/t are reported as the test result, the blending of these numbers produce the same result on a blended sample as is derived from calculation, as long as the measured test parameter and conversion to power equation are also linear. However, when the test result is non-linear when plotted against kWh/t, the blending on paper may not match the testing of the actual blended material. In this non-linear case, the results are not really suitable for easy and accurate geometallurgical modelling.

If the inherent accuracy of the test being used for final mill design is not within plus or minus 5% of the true value, as confirmed by benchmarking, it is not the best practice considering that this level of accuracy is commercially available (Starkey and Larbi). When requesting a quote for test work services the vendor should be asked to provide proof that the test work accuracy is sufficient for the work being done. If it is not, other sources of supply should be sought out.

There are two parts to SAG mill design best practices. First is to choose the SAG mill (chamber size and power discussed above) that will process the design feed every day, including those days when mostly hard ore is available. Second is to engineer the grinding plant so that optimization can be done quickly. In this regard, ancillary equipment, process

flow and the layout need to be professionally set up. For instance, if the transfer size cannot be sampled and measured, it will add weeks if not months to an otherwise successful start-up, because adjustment to the SAG mill feed tonnage can only be properly made when the product size can be measured and controlled on a daily basis with up to date information. Other parts of the engineering design are also critical, such as getting the correct pumps, cyclones and conveyors, to run trouble free, with proper allowance for circulating loads.

The last item of Best Practices is not to by-pass the final steps required prior to purchasing the grinding mills. The fact is that some mills are chosen because the cost was determined during the Feasibility Study and there is no time available to confirm that the mill size is adequate prior to purchase. When this happens, the whole project is put at risk because the required extra capital to buy the correct mill can be multiplied by 10 to provide the required grinding capacity by retrofitting after start-up, and the operating costs after a retrofit will be higher as well. There are professional services available where mill size and power can be verified to within 5% of actual in less than 2 months, so there is no reason for not confirming a mill size prior to purchase. The cost of retrofitting, lost production and possible legal fees and damages for a failed design will make checking worthwhile for everyone concerned.

Client Expectations

The client's expectations used to be simple and straightforward: .start on time, with no budget overrun, and achieve design tonnage immediately. But over the years the concept of "Production Ramp Up" gave credence to starting up at lower tonnage and today the term has become "Normal Production Ramp Up" as we saw in the write ups from a recent Canadian project that did not come close to achieving design tonnage on day one.

For those who have never witnessed a project starting up on time, on budget, at design tonnage and with no capital revisions, the author confirms that over the years this has always been possible. Kidd Creek in Timmins, ON, Canada (rod/ball grinding) started at full tonnage on day one in 1966 and did not shut down for 30 days. Gays River lead zinc (rod/ball grinding) started on time, at tonnage and 10% under budget in 1979.

The Lake Shore Gold startup (2014), see below, is an example of a good SAG start-up.

SAG milling is different and has taken a longer time to become reliable technology. During the last 20 years it has been replacing rod/ball grinding for new projects because the lower ore grades now available must be mined at much higher tonnages to be profitable. At the same time the expertise to design and operate these SAG plants needed to be developed. Private technologies for SAG mill design have not helped yet have dominated the market prior to 2000. The first fully open design technology for SAG mills was not invented until 2002 and was first offered commercially in 2004 as a patented method. Only in the last 5 years has this open technology come into widespread use. It is not surprising that clients trust no one, buy the cheapest SAG mill available, and use trial and error methods.

In the past, the way to correctly operate a SAG mill was not fully understood. High loading of the SAG mill, and high power usage were thought to produce higher tonnage. On hard ores this is not true and leads to misjudging of the capacity of a given SAG mill which may

have the required power for more tonnes but not the chamber size to use it productively to increase throughput. For original lifters, the phenomenon of maximizing tonnage at 26% load and 75% critical speed is now becoming fully accepted by mill operators and designers.

Recent Start-Ups

This could be a subject for a separate paper. In this paper the corrective actions needed to avoid failed cash flow prediction are alluded to. To indicate the magnitude of the problem, eleven start-ups are listed below. This is not a complete list. It includes only those plants of which the authors are aware of the details at this time.

PLANT	RESULT
Mercator, USA	Tonnage achieved using used mills.
Tenke Fungarume, DRC	Tonnage achieved at start up.
Tabokoto, Mali	Tonnage achieved.
Climax Molybdenum, USA and Thompson)	Tonnage achieved. (Starkey, Meadows, Senchenko,
Alexandrovskoe, Russia and Starkey)	Tonnage achieved on hard ore. (Kulikov, Senchenko,
Beleya Gora, Russia	Tonnage achieved on soft ore.
Lake Shore Gold, Canada	Tonnage achieved in three weeks. (Felsher)
Detour Lake, Canada	Tonnage achieved after conveying issues resolved.
Osisko Malartic, Canada	Pre-crushing added. (Osisko Annual Report, 2013)
Copper Mountain, Canada and Marks)	Pre-crushing required. (Vijfeijken, Filidore, Walbert,
Mount Milligan, Canada	Pre-crushing required.

In summary, the first eight plants (above) measured SAG mill design pinion energy and variability hardness in kWh/t, while the last three did not.

Myths

The history of SAG mill design technology development has been hampered by private interests controlling the design methods, and by misunderstandings and misconceptions that have been around since the introduction of autogenous grinding in the 1950's. These misunderstandings are being propagated even to this very day - with new ones added.

Older myths include the following:

MYTH	EXPLANATION
Ore has a critical size problem.	Not enough power for that t/h.
Representative sample for good design.	Only ore that a SAG mill will never see.
Increase AG throughput with coarser feed.	Coarser than 200 mm decreases t/h.
Peak power equals peak tonnage.	Not so. Power peaks at 35% load, t/h at 26%.
Testing shows ore is 'amenable' to SAG.	Every ore is amenable to SAG technology.

More recent myths include:

MYTH	EXPLANATION
Transfer size (T_{80}) doesn't matter.	T_{80} controls power split and SAG/ball power. Failure to provide size control of the T_{80} is one of the biggest problems in SAG milling today.
Design by simulation and comparison.	Other mines don't matter. Design should be based on client's ore. New flow sheets and provision for the future can now be considered.

By giving credence to these myths, our ability to deal with the real design challenges is reduced and opportunities to provide for future expansion are nearly impossible to implement in a capital cost effective way. New design should be based on engineering calculations done from test work results on the client's own ore. To do otherwise is to make a mockery of the principle that all ores should be tested prior to building a process plant.

"Simulation is a great tool for optimization, but should never be used to design greenfield SAG grinding plants (sic)".

(Statement by Mr. Ivan Mullany, V.P. Metallurgy, Barrick, at 2011 Toronto CMP meeting).

Misunderstandings

Misunderstandings occur frequently but are difficult to discuss because of the obscurity that exists regarding best SAG mill design practices. An example comes from the way in which SAG mills are designed for the apparent lowest capital cost – with little or no regard to what operating costs will be, or what contingency should be provided to ensure that design tonnage can be achieved at all times. Selection of the hardness variability percentile for design relates directly to the capacity contingency of the new grinding facility. A fundamental principle that was learned more than 40 years ago by the author, was to ensure that a client will always have the comminution facilities installed in a new plant to achieve design tonnage at all times. That was the process design engineer's job.

Today sadly that is not done or considered necessary. Today with SAG milling, because that equipment does the job of replacing secondary crushing, tertiary crushing, rod milling and in some case ball milling, the ore hardness variability is a much bigger component in plant throughput variability. Crushing dominates its effect on the ore by treating ores of all hardnesses at a relatively constant throughput. This is why crushing is more energy efficient.

The variability does not manifest itself until the tumbling mills following primary crushing are used. This is why a SAG or AG mill is so much more sensitive to hardness variability. This variability can be dealt with by installing a proper ore blending facility in front of the plant as is often done to control impurities in the iron ore business, or by installing the proper SAG mill. The latter solution is much more cost effective.

This leads directly to the next and most significant problem in today's design and operation. Many engineer's feel that the best practices way to operate a SAG mill is to push its capacity to the limit at all times. This deliberately causes the tonnage to fluctuate, in some cases as much as $\pm 20\%$. In a gold plant with 48 hours of retention time that may not be a big problem as long as the grind size is steady, but in a float plant that fluctuation can cause serious metallurgical losses by creating instability in the flotation circuits.

If we read the design specifications for a process plant, we do not read - capacity between 800 and 1200 t/h, we see 1000 t/h. It is not insignificant that if this specification is properly interpreted, that the SAG mill will be larger than the fluctuating tonnage scenario. This in a nutshell is why SAG mills are often too small and design capacity so difficult to achieve.

If the ore sent for processing at startup is harder than normal, design tonnage will be impossible if the process design specification has not been properly implemented. If the tonnage specification is respected, the SAG mill will be larger and starting up at design tonnage will be easy. When common sense, accurate hardness measurements and sound engineering calculations to determine mill sizes are implemented, the task of starting a plant at design tonnage becomes a simple task.

Another misunderstanding comes from the use of inaccurate testing to determine ore hardness, and the test result being in some other units than t/h. Until measuring SAG pinion energy for a sample in kWh/t is standard, the design exercise will be difficult. Numerically speaking, when kWh/t are measured, the results can be combined proportionally on paper or by testing of the same blended proportions to give the same test result as the calculation. This has been proven in the laboratory. By using outdated measurements and overly complicated computational techniques, we have effectively blocked the path to a rational understanding of numbers to allow intuitive and effective decisions to be made by the engineers at a mine who are charged with making the mine to mill process work. If only those with vast experience in the field can perform the design work then new inductees to the industry will be ineffective for a number of years. The design methods must therefore be simplified to the point where everyone in the business can properly design a SAG mill. Until this is done the mistakes will continue.

The most astonishing misunderstanding of all is to ask why the financial drivers for a new project are so flagrantly ignored. In a Feasibility Study, capital costs, operating costs, revenue, discounted cash flow and rate of return are all calculated, as if these numbers are precise. When they are not, financial chaos will result.

If the capital cost of the selected grinding equipment will not deliver design tonnage, then there are two additive errors in the DCF calculation. More capital and less profit to repay it.

The Big Picture - Financing

At this point we must agree that owners and investors are unhappy because financial losses are measured in the order of hundreds of millions of dollars and if technical experts do not correct this problem immediately, severe legal problems could follow.

Project financing, revenue from production, capital and operating costs, are all things that are required to be defined in a credible Feasibility Study. If the tonnage is not possible, and more capital needs to be spent to achieve design tonnage, what is the significance of the discounted rate of return that is so meticulously calculated as if it were true? If these things cannot be defined accurately, then the whole purpose of doing financial analysis is pointless.

The casual way that these discounted cash flow numbers are regarded will rapidly become a thing of the past. Since it is now possible to measure ore hardness within 5%, it is also possible, with a reasonable understanding of the mining methods to be used, to measure the overall ore hardness of planned mill feed and purchase a SAG mill that is big enough to grind the required tonnage. It is inconceivable that this lack of financial and technical discipline will be allowed to continue. If the mining industry do not make this happen for the benefit of the investors, then those investors will ensure that larger and more sophisticated entities will purchase the mines and enforce the disciplines that are required to give shareholders their share of the rewards for finding and bringing a new mine into production. Entrepreneurs thrive on seeing opportunities and making good things happen.

Required information that is beyond the scope of this discussion, includes calculating the impact of errors in mill design on DCF and revenue for current improperly designed projects. The basis should be actual results studied in the context of published 43-101 reports. It is already known that the magnitude of the revenue shortfalls and the capital overruns add up to astonishing totals. Unfortunately this is money that comes directly from shareholder investments. Instead of returns, the shareholders are being asked to either invest more or suffer dilution because of this revenue shortfall. Either way, it is unacceptable.

Conclusions

The conclusions derived here are urgent.

A paradigm shift in how SAG mills are designed and purchased is required. Owners should never ask a mill vendor to size the SAG mill because the owner's interest in making design tonnage at all times will not be respected. Mill vendors have a conflict of interest. If their price is not low, they will not win the order.

Engineering companies need to be more independent and either retain proper design expertise or provide training for their staff to do the job properly. Excellent SAG mill design courses are available.

The cost of a poorly designed SAG mill to an owner is so large that it cannot be ignored. Adequate SAG mill design work must be done prior to initiating the project because it is not

possible to conduct a meaningful financial analysis for a project unless the SAG mill has been properly designed to deliver the design t/h - and revenue.

To speed up the confirmation of mill sizes before purchase, the most sophisticated and accurate hardness measurements must be used, regardless of what data was used in the feasibility study. Because +/- 5% accuracy is available, the confirmatory tests required can be restricted to ten and can be completed in less than two months.

It is possible to design and start-up a SAG mill at design t/h from day one. This is a fact.

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