Recent International Concentrator Start-ups
Do and Don’ts for Effective Grinding Mill Design.
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1. ABSTRACT

A review of recent concentrator start-ups has been done to examine the methods that were used to design the grinding circuits for these new plants and the results achieved. A number of these start-ups were reported at SAG 2011. Large differences between design tonnage and actual tonnage were reported, with actual tonnage both above and below the design target by wide margins. This paper will examine some of these international plant start-ups, compare design tonnage versus actual tonnage achieved and review the sampling programs, the grinding test procedures, and mill design and sizing methods that were used. From this, dos and don't's for effective grinding mill design have been derived.

At the same conference (SAG 2011), recommended design and test selection procedures were presented. These have been compared to the findings from the projects referred to above and are judged to be helpful in avoiding slow and delayed start-up and ongoing operational problems.

2. INTRODUCTION

The importance of accurate grinding mill design for SAG grinding circuits cannot be overstated. With the advent of large SAG mills up to and over 40 ft in diameter, the possibility for having all of one's eggs in one basket is very real as single line circuits have become the norm except in cases of extremely hard ore or extremely high tonnage requirements or a combination of both. It is therefore incumbent on mill designers to understand the hardness variability in a new ore deposit so that a SAG mill can be chosen that properly matches the ore body and the exploitation method chosen for that ore body. Failure to achieve design tonnage during the early stages of a plant start-up can seriously impair the cash flow during the first year and make the decision to save capital cost on the purchase of a smaller than required SAG mill, look like a poor choice if the net impact on Project NPV fails to meet the project's financial goals.

The purpose of this paper is to examine recent international start-ups and find out what works and what does not. During the course of preparing this paper it was realized that in some cases only the start-up was described and the design information was not presented. As we move forward in creating good grinding circuit designs, there are a number of challenges that need to be addressed. And perhaps the most important of these is to base a green field design on hardness measurements from a client's own ore body and not to rely on simulation techniques which make the design hard to confirm and subject to error because no two deposits are alike.

It is also important to realize that with the advent of SAG milling in the late 1950's, the design techniques for SAG mills have been owned and supplied to clients based on technologies that are privately owned and which use proprietary information. Prior to that, Allis Chalmers and Fred Bond in particular, gave the industry the Bond rod and ball mill work index techniques that were open and which have been used by all in our industry for more than 50 years. The authors recommend that we step back to first principles and use methods that everyone can understand.

3. PROJECTS

Five projects reported from the SAG 2011 Conference have been studied in this paper. They include; Phu Kam (Cu/Au) in Laos, Andacollo (Cu/Au) in Chile, Gibraltar (Cu/Mo) in Canada, Yanacocha (Au) in Peru, Damang (Au) in Ghana and are listed in Table 1 below.

Table 1 – INTERNATIONAL START-UPS

PROJECT	SAG MILL		# BM	BALL MILLS		AVAIL.	MILL DESIGN DATA			TYPE	REMARKS
	D x L, ft	*MW*		*D x L, ft*	*MW*	*%*	*Cap, t/h*	*kWh/t*	*P80 - μ*		
Phu Kam	34' x 20'	13.0	1	24' x 40'	13.0	91.3	1,500	17.3	106	Bond	*2nd BM will increase cap. From*
	17.5' EGL	twin			twin		@ start-up			& DWI	*1500 to 2000 t/h on hard ore.*
Andacollo	36'x22'	16.8	2	25' x 40.5'	14.2	94% calc.	2,420	18.6	na	Historical	*Started auto mill and 1 BM.*
	36'x20'EGL	gearless			twin						*Ramp up to full prod 7 months*
Gibraltar	34'x17'	9.7	6	13.5' x 20'	1.85	91% calc.	2,079	10.0	300	Operating	*SAG mill added to 3 line rod*
	14.75'EGL	twin			single						*ball mill plant. All mills same.*
Yanacocha	32'x32'	16.5	0	No BM	--	92% calc.	620	26.6	75	Bond BM	*Single stage SAG mill.*
	29.5' EGL	gearless									*t/h exceeded at P80 of 150 μ*
Damang	26' x 18'	5.8	1	20' x 29.5'	5.8	~ 91.5%	650	17.8	150	JK & Bond	*50:50 blend hard soft, 150 μ*
	15.5' EGL	single			single		300/400 on hard ore.				*Lower tonnage on hard ore.*

These projects involved SAG mills from 26 to 36 ft in diameter, with installed power in the range 9.7 to 16.8 MW using single, twin pinion, and gearless technology for drives over 16 MW. The ball mills used varied from 13.5 to 25 ft in diameter, with installed power in the range 1.85 to 14.2 MW using single and twin pinion technology. Results from these papers are now discussed in order.

Phu Kam was successful using a combination of Bond RM, BM and DWI tests. The design tonnage of 1,500 t/h was achieved easily and harder future ore was allowed for by ordering a second 13 MW ball mill. This design reflects a number of solid decisions regarding staged investment in grinding hardware versus required capacity to treat harder ores in the future.

The Andacollo start-up was orderly and well planned. Initially the primary mill was started with no steel (as an AG mill). Steel additions and increasing tonnage followed with the achievement of commercial production seven months after start-up. However, operational problem had to be sorted out to do this. Larger (5.5 inch) SAG balls were added, a secondary impact bed for the SAG mill discharge was provided to prevent wear and provide better distribution to the screen, a second magnet was added to protect the pebble crushers, larger cyclone feed pumps were installed, and cyclone underflow launders were modified to provide better transport of steel chips to the ball mills. No design data was shown in the paper but it was clear that during over 25 years of studying this project, good design information was available.

Gibraltar was another successful SAG start-up. In this case a three line rod/ball mill plant was converted to a SAG operation with six identical ball mills following in parallel configuration. Although no specific test data was presented in the paper, it is clear that the operating data obtained from previous years allowed the proper assessment of required SAG mill power.

The Yanacocha gold operation is a single stage SAG mill that was designed to treat 620 t/h at a grind P80 of 75 microns. This was not possible to achieve and grind was sacrificed for tonnage when it was realized that the recovery loss of gold at a P80 of 150 microns was less than 2%. Optimization with JK data did not resolve the problem, probably because the mill lacked power to achieve the final grind of 75 microns.

Damang was successful treating a 50:50 blend of hard and soft ore at the design rate of 650 t/h. However hard ore alone was a problem because throughput dropped below 400 t/h. Here JK and Bond test work was done to properly understand the situation but because the hard ore was SAG limited, the problem could not be solved by adding a second ball mill. The treatment of design tonnage will require the installation of a crusher to crush part of the SAG mill feed and by-pass it directly to the ball mill.

4. DISCUSSION AND OBSERVATIONS

Based on the above history and on recent experiences across a variety of projects, some relevant observations are summarized.

1. The need for a basic understanding of a mineral deposit and it's exploitation must never be underestimated. It is key from the onset of the project development to combine the geologist, mining engineer and metallurgist’s skills.

2. There is a need to carry out multiple small scale tests for the comminution circuit design and cross check the information back and forth for consistency. Homogeneous deposits may have existed in the ferrous mining industry but for base metals and gold, multiple samples are required due to the hardness variability of the gangue minerals that host the metallic minerals of interest.

3. Getting the appropriate number of samples and meaningfulness of the samples is key rather than taking endless samples that are not always relevant to the goal of the program. Some tests notably SMC and JK Dropweight are not effective on composite samples from many drill holes. Other methods are excellent in using composite samples for hardness measurements.

4. In any comminution circuit development, consideration should be taken of the location of the concentrator, the associated infrastructure, electrical supply and logistics. For example HPGR roll replacement by normal freighting methods in certain countries may be unrealistic.

5. Sizing grinding circuits on bond ball mill work indices can lead to erroneous results. The authors have seen several examples that were based only on bond and the SAG grinding characteristics were either masked, misinterpreted or not measured at all.

6. Relevance of spacial separation between drill holes, samples and hardness variability with depth needs to be considered.

7. Plant availability information should be benchmarked with corresponding projects in the region and knowing the maintenance/operational support and logistical challenges. Many circuits in North and South America are typically designed at 90 to 92 % availability. Over a period of three to five years this matures to greater than 94 %.

8. Make sure the P80 grind size versus metal recovery are well understood in the early stages and that the sensitivity analysis is run for the optimum economical grind size. Changes in the grind P80 will affect the ball mill sizing and overall cost of the circuit.

9. Make sure testing laboratories understand the relation of actual grind size requirement and closing screen size for Bond Ball Mill Work Index testing. Sometimes the Bond BM Wi varies dramatically at other than the design product size. A good rule of thumb is to multiply the P_{80} in microns by 1.33 to estimate the closing screen size in microns. In addition, make sure the test mill geometry and conditions are industry standards and not unusual.

10. Once the preliminary mill sizing requirements have been established always look at industry benchmarking. For example what size 36 ft diameter SAG mills have been supplied and what is the related F/F and EGL, together with the corresponding motor. At the same time be aware that high SG of the ore to be processed, high steel load, and allowance for overspeeding the SAG mill, all cause the size of the SAG mill motor to be increased.

11. Make sure all the mill terminology i.e. F/F and EGL are well defined and clearly understood by all parties. Stay within the industry norms of D:L ratios and have full practical back up. In the results reported in this paper it is clear that in some cases EGL and F/F measurements may have been misreported.

12. Check the corresponding mill motor size and review in terms of power per foot length etc. Make sure the power rating is validated by an operating mill and that the mill motor is sufficiently sized to take into account a series of operating scenarios – mill speed, total and ball charge, liner conditions etc.

13. Don't let commercial decisions override the technical requirements of the grinding circuit design. The grinding circuit is a significant capital cost requirement and should not be compromised. There have been some recent events relating to saving on motor costs and drive train requirements that have been irresponsible. The SAG mill is the income generator for the project and must be sized according to what is required for throughput, not what is cheapest to purchase.

14. Check the SAG to Ball Mill power split falls within industry norms and is fully defendable. There are now ways available to measure the SAG and ball mill pinion energy and these methods should be used when hard ore will be treated in the SAG mill.

15. Always make a benchmark review against other similarly sized projects in terms of capacity, power rating etc and make sure it holds up to this test. Consider visiting some of the similar sized projects for lessons learned from operating conditions and maintenance aspects for these ores.

16. Pay attention to all the ancillary equipment including cyclone feed pumps and cyclones together with the mill relining equipment.

17. Keep the grinding circuit layout simple, proven and maintenance friendly. Pay particular attention to how liners are brought in and out of the plant, access to the cyclone feed pumps etc.

18. Start off the plant with a standard proven robust control strategy and then develop a plan to implement an expert control system – however emphasis should first be to understand the operation and capability of the plant itself. Then consider implementing an expert control system. Until manual control is well understood it is difficult to automate the grinding process.

19. Finally spend the necessary money on sample acquisition, testing and variability studies to ensure a robust design. As time progresses, the need to get a faster more accurate design will emerge as a way to overcome long lead delivery times for grinding equipment.

20. A truism that emerged from the Timmins camp in the early sixties was "good engineering does not start until the money runs out". We are not suggesting that the money is running out but simply that prudence is required when spending money on mill designs. We the suppliers of grinding test work, grinding circuit designs, SAG and ball mills, and our clients should expect nothing less than excellent designs in a timely fashion and at reasonable cost. When big test programs are undertaken, there is a delay involved in getting the results in time to be used. In times of high demand for grinding mills, the value of an accurate answer in two to three months can significantly improve mill delivery times.

5. CONCLUSIONS

Considering these five SAG 2011 start-ups, the conclusion is obvious that three plants achieved target production, one plant was successful at start-up but could not easily be modified for hard future ore, and one plant achieved t/h but not grind.

It is not clear why these latter two plants had problems. Probably a combination of things were involved. Lack of enough test data, lack of a definitive design procedure, lack of understanding of how a SAG mill operates and lack of agreement with other methods may have been involved.

We can say however that three recommended features of a good design were missing in these cases. First, adequate power was not provided to treat the start-up ores in two cases. Provision to treat harder ore was omitted in one case and failure to provide an easy path to expand tonnage on the same ore was not included in the same case.

Even though Yanacocha could not achieve design grind, the addition of a ball mill would solve that problem and allow for expansion as well, depending on the size of ball mill added.

Hard ores in the SAG mill are called SAG limited ores. Expansion of such plants cannot be done by adding a ball mill. Damang should have considered the SAG to ball mill hardness ratio and installed a larger SAG mill that could have better matched the required or expanded tonnage capacity. SAG limited ore demands that SAG mill power be greater than the ball mill because fine grinding can be done in a SAG mill but coarse grinding cannot be done in a ball mill.

There are many ways to accomplish a satisfactory mill design. Some are intuitive and the ore hardness measurements and mill sizing results can be understood by all. SAGDesign technology including mill sizing methods are being taught in undergraduate courses in Canada and in other countries on special occasions. Other methods are proprietary and are the output from simulation or other proprietary computer programs. We encourage clients to use methods that they are familiar with but also to recognize that new and better methods are emerging that are transparent and teachable.

Finally, always spend time and effort on due diligence reviews of similarly sized plants, examining design versus actual performance, and pay attention to the lessons learned after commissioning is complete.

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Note: *Denotes paper given at the "International AG and SAG Grinding Technology, 2011" Conference held in Vancouver B.C. Canada. Six papers are referenced herein.