Attachment 1: Survey Scope of Work

The objective of the audit is to conduct a benchmarking "health checkup" on the grinding circuit for one ball mill line. This will provide a basis for assessing the overall grinding efficiency of the circuit and provide base-line data for future circuit optimization. A secondary objective is to provide model calibration information for a Mine to Mill optimization evaluation.

The audit is divided into three stages:

- A "Stage 0" consisting of work done at Alex G. Doll Consulting Limited (AGD) office to prepare ahead of the survey.
- A "Stage 1" consisting of a basic circuit survey that does not involve any mill shutdowns.
- A "Stage 2" that consists of mill crash stop. This stage can be done during the Stage 1 survey, but is recommended to be postponed to coincide with a scheduled mill shutdown.

AGD uses a variety of types of models to benchmark mill performance, as depicted in Figure 1. Phase 1 will collect data suitable for Specific Energy Models and Population Balance Models. Phase 2 will collect data suitable for Power Draw Models. Discrete Element Models (DEM) are not part of this current proposal, but can be provided in a future liner optimization program.

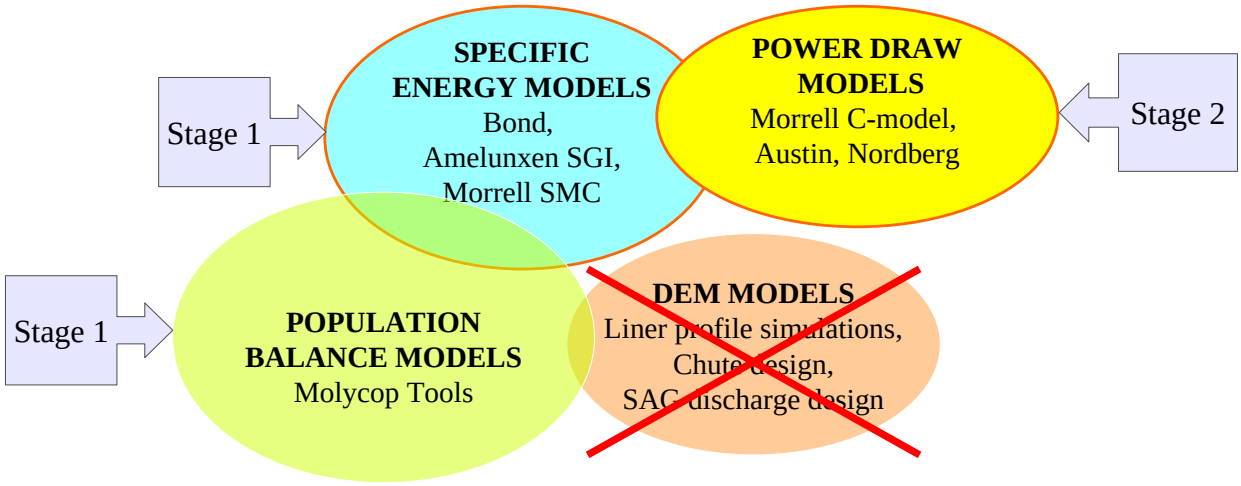

Figure 1: Examples of models used in circuit benchmarking

Stage 0: Review existing information

The mine will provide AGD with the following information in order to set up mathematical models and other calculations for the grinding circuit prior to the survey:

- Process flow diagram and data sheets for mills and their main motors.
- Control system (DCS) database dump of the past six months of operating data on a 5-minute interval for all important control system tags in the database, including:
  - tertiary crusher product (fresh feed) belt weightometer, dry t/h (or provide an ore moisture measurement if weightometer is wet t/h)
  - feed size camera results, if available
  - mill load cell readings, if available
  - bearing pressure readings
  - mill speed, RPM (or motor RPM)
  - power draw, kW (each mill)
  - electrical single-line diagram showing the measurement position of the mill power
  - if induction motors: provide the operating power factor
  - flow and density measurements for cyclone feed
  - water addition, % solids, setpoint for the sump & ball mill feed
  - hydrocyclone pack pressure for pack
  - hydrocyclone overflow particle size P_{80} according to online particle size monitor
  - crushing circuit fresh feed rate and power draw for all crushing lines
- Liner drawings as-new (provide vendor’s drawings) and a sketch with thickness measurements of worn liners after removal from mills.
- Photographs of the mill motor name-plates showing the rated RPM, power, efficiency, etc.
- Description of the motor drive train (Eg. motor → gearbox → clutch → pinion → mill bull gear). A photo showing the arrangement would be convenient if the drive train fits into a single frame.
- Dates and details of liner changes during the past twelve months, and planned changes in the upcoming twelve months.

Stage 1: Circuit efficiency survey (mills operating)

This survey will consist of a specific energy benchmarking check versus power-based comminution models and a Functional Performance efficiency determination for the ball milling circuit. It provides an ore characterization using laboratory tests and the corresponding circuit operating behaviour.

Figure 2: Example feed sample taken from stockpile feed belt

A belt sample of 40 kg is collected for laboratory grindability testing. The sample is to represent the one-hour sampling campaign in the grinding circuit. If the belt cut is taken ahead of the fine ore bin (recommended), then sufficient time must be allowed for the sampled material to pass through the bin and appear in the grinding circuit. The belt sample will be put into a sample barrel or multiple 5-gal buckets and transported to a metallurgical lab capable of generating the following tests:

- Granulometry from an appropriate top size down to 74 µm,
- Bond work index for rod milling (1,180 µm closing screen)
- Bond work index for ball milling (×3: 74 µm, 106 µm, & 150 µm closing screen), and
- Moisture assay.

The testwork report shall include all the details of the determination of the tests including the particle size distribution of feed and product, and per-cycle grams per revolution for the Bond tumbling tests.

The survey will consist of a one-hour period of stable operation where the ore feed to the grinding circuit is consistent and, as much as possible, representative of the ore sample collected for grindability testing. Mill speeds and power draw will be held constant (as much as possible). Slurry samples will be cut every 10 minutes from the following locations:

- BM hydrocyclone overflow
- BM hydrocyclone underflow
- BM mill discharge
- (if piping allows) cyclone feed for BM

Each slurry sample will be cut using cross-stream samplers and transferred to a sample bucket labelled as described later. Cuts will alternate, the first cut goes into a “Cut A” bucket and the second into the “Cut B” bucket.

Slurry samples are expected to require two or four buckets each, for a total volume of the order of 25-50 Litres. After the survey, the slurry for each “A” or “B” sample is analyzed for the following:

- Weight percent solids.
- Granulometry from an appropriate top size down to 74 µm.

The “A” and “B” samples will have separate %solid determinations and be sieved separately at the laboratory to generate duplicate size distributions as a quality control assessment of circuit stability.

Figure 3: Example hydrocyclone underflow sample transfer to bucket

The mass balance will be calculated around the ball mill circuit, and specific energy consumption of the milling stage will be calculated by AGD. Provide the following DCS data on a one-minute basis for the period from one hour before the survey to one hour after the survey:

- feed rate of fresh feed, wet t/h (tertiary crusher product to the survey grinding line)
- feed size camera results, if available
- bearing pressure readings
- mill speed, RPM (or motor RPM)
- power draw, kW for the ball mill
- water addition, % solids, setpoint for the sump & ball mill
- flow meter and density measurements for hydrocyclone feed (m^3/h and t/m^3)
- hydrocyclone pressure
- crushing circuit fresh feed rate and power draw for all lines

Each tertiary crusher product sample bucket shall be labelled with the following information:

- The project number assigned by the comminution laboratory.
- The name of the mine.
- The sample contained in the bucket.
- Date the sample was collected.
- The sequence number of this bucket within the sample.

Program *abc* *Name Of* Mine *Tertiary crusher product* date: *yyyy-mm-dd* Bucket *1* of *4*

Stage 2: Mill power draw survey (crash-stop of mills)

The ball mill crash stop is only required if the Stage 1 survey suggests a problem with the grindability efficiency of the ball mills or to construct liner wear models. If there is no problem in the ball mills, then the Stage 2 assessment of the ball mills is not optional.

The crash-stop of a mill determines the total charge level. The level will be measured by a laser scanner inserted into the stopped mill. If the mine does not have a laser scanner, then one can be rented from an OEM like Metso:Outotec or from a specialized contractor like Coding Metrology.

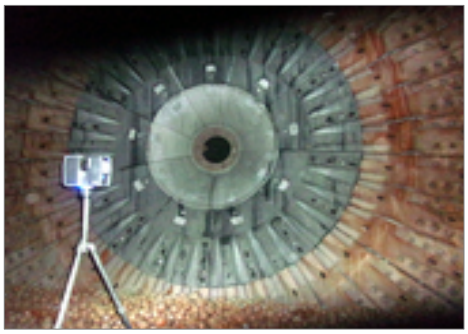

Figure 4: Coding Metrology laser scanner in a SAG mill

The power draw and velocity of the mill immediately before the crash stop will be read from the control system along with the feed rate and the hydrocyclone feed flow and density.

No mineral samples are required for this analysis, but the rock density (t/m³) is required to operate the models. The rock density from the Stage 1 analysis can be used if the rock type milled during the time of the Stage 2 crash stop is the same as the rock type milled during the Stage 1 sampling. Otherwise, the daily cyclone overflow composite can be analyzed for specific gravity to provide a density measurement.

The liner thickness and lifter (or wave) heights shall be measured to provide both a profile of ball mill lifters, and a measurement of the effective diameter and grinding length of the mill interior. The laser scanner systems often have the capability to deliver these measurements as part of their survey report.

The results will be entered into tumbling mill power draw models, such as the Austin SAG model or the Morrell C-model, and the model predictions will be benchmarked to the actual performance recorded in the survey.

Deliverables – Survey

The main objective of the survey is the recommendation of operating conditions that provide maximum circuit throughput at a XXX µm product P_{80} size. This requires a base-line of how the circuit is operating and is configured. The Stage 1 report sections are intended to measure the overall health of the grinding circuit and determine how efficiently it is grinding the rock versus the benchmark models based on the laboratory grindability. The total circuit specific energy consumption (kWh/t) will be measured in the plant and compared to the model predictions. A Functional

Performance assessment of the classification efficiency and grindability efficiency will be performed and will indicate if more optimization of the ball milling circuit is warranted. If the Functional Performance efficiencies are all “normal”, then the ball mill circuit can be declared “healthy” and no further assessment of this equipment is required.

The Stage 2 report sections look closer at the ability of a mill to draw power from the motor. The mill and charge geometry observed in the study will be entered into models to predict what a normal mill with these dimensions should be able to draw from the motor. The actual motor power draw is then compared to the prediction to validate how efficiently the mill liner and other subsystems are functioning.

In the event that equipment in the grinding circuit fail their benchmarking checks, then remedies will be proposed or further investigation will be suggested. The model predictions for the “optimal” throughput for the mineral observed in the Stage 1 and the recommended operating conditions for the ball mills will be provided.

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