TECHNICAL MEMORANDUM

14 February 2007

TO: FILE NOTE
FROM: ALEX DOLL, ALEX G DOLL CONSULTING LTD.
SUBJECT: JK BALL MILL MODEL NOTES

Summary:

Review of the JKMRC *Mineral Comminution Circuits* textbook (Reference 1), and discussions with practitioners of the JKSimMet software have led to the following simplified description of the operation of the JK method for modelling a ball mill. A scenario of scaling up a pilot plant test to a full sized circuit is assumed in this discussion.

The material balance modelling (including projected product sizes) is handled separately from the mill power draw estimate. The material balance makes use of results of a “ball mill modified drop weight” test to produce a combination of appearance function (a matrix, ***A***) and two energy related terms 'A' and 'b'. Unfortunately JK mixes terminology using the same variable “A” for these two different purposes.

The power draw estimate is based mostly on the Bond ball mill formula where the feed to the ball mill is the projected SAG mill discharge that has passed through a “phantom cyclone”.

In the absence of testwork, many values used in the JKSimMet model may be assumed based on other surveyed mines or on default values built into the model. There is also a curve fitting exercise that happens in the material balance method that requires input from the operator running the fit.

Testwork

In a situation where a SAG mill/ball mill pilot plant test has been run, the purpose of the JKSimMet simulation is to first calibrate the models to match the pilot plant results, and then use those calibrated models to estimate performance of full sized process equipment. Two other laboratory tests are used along with the pilot plant results:

1. The power estimate requires a standard Bond ball mill work index with a closing screen chosen to achieve a circuit P_{80} reasonably close to the pilot plant P_{80}.
2. The material balance requires a ball mill drop weight test to produce an appearance matrix (particle size distribution observed from crushing a particle of roughly 5 mm diameter).

Material Balance Modelling

The "equation of state" that is used in the JKSimMet simulation is (equation 9.8 in the JKMRC text):

$$\vec{f}-\vec{p}\cdot\left(\frac{\vec{r}}{\vec{d}}\right)+\boldsymbol{A}\,\vec{p}\cdot\left(\frac{\vec{r}}{\vec{d}}\right)-\vec{p}=0$$

where,

f is a vector of feed retain fractions (kg/s),

r is a vector of the rate (frequency) at which each fraction breaks (1/s),

p is a vector of product retain fractions (kg/s),

d is a vector of the rate (velocity) of discharge rate from the mill of each fraction (1/s), and

A is the matrix of what sizes each fraction breaks into.

The drop weight test that is done for SAG milling produces no information of any value to this equation of state. Only if a ball milling drop weight test is performed can the matrix ***A*** be determined for the ore under test. In the absence of ball mill drop weight test (most customers don't pay for any to be done), then the matrix ***A*** must be populated either from results of other mines, or using the "default" values published by Broadbent and Calcott in 1956. If these default values are used, then the appearance matrix will almost always over-estimate the amount of coarse material in the ball mill discharge (refer to Figure 1). This results in an overestimate of the ball mill circulating load and power demand.

The equation of state is now fitted to the pilot plant feed and product size distributions resulting in the quotient $\frac{\vec{r}}{\vec{d}}$ being specified.

The vector *d* can be populated using a "standard mill" (unit-size) to "production mill" (full-size) conversion described in equation 9.9 of the JKMRC text:

$$\vec{d}=\vec{d}^{x}\left(\frac{4Q}{D^{2}L}\right)$$

where,

d^x is the normalized discharge vector of a standard mill,

Q is the flow through the full sized mill,

D is the full sized mill diameter, and

L is the full sized mill length.

The normalized discharge vector is almost always unity for all but the coarsest size fractions due to the assumption that the ball mill is a perfectly mixed system. This assumption allows the vector *d* to be calculated and then the breakage rate vector *r* is calculated from the fitted quotient described earlier.

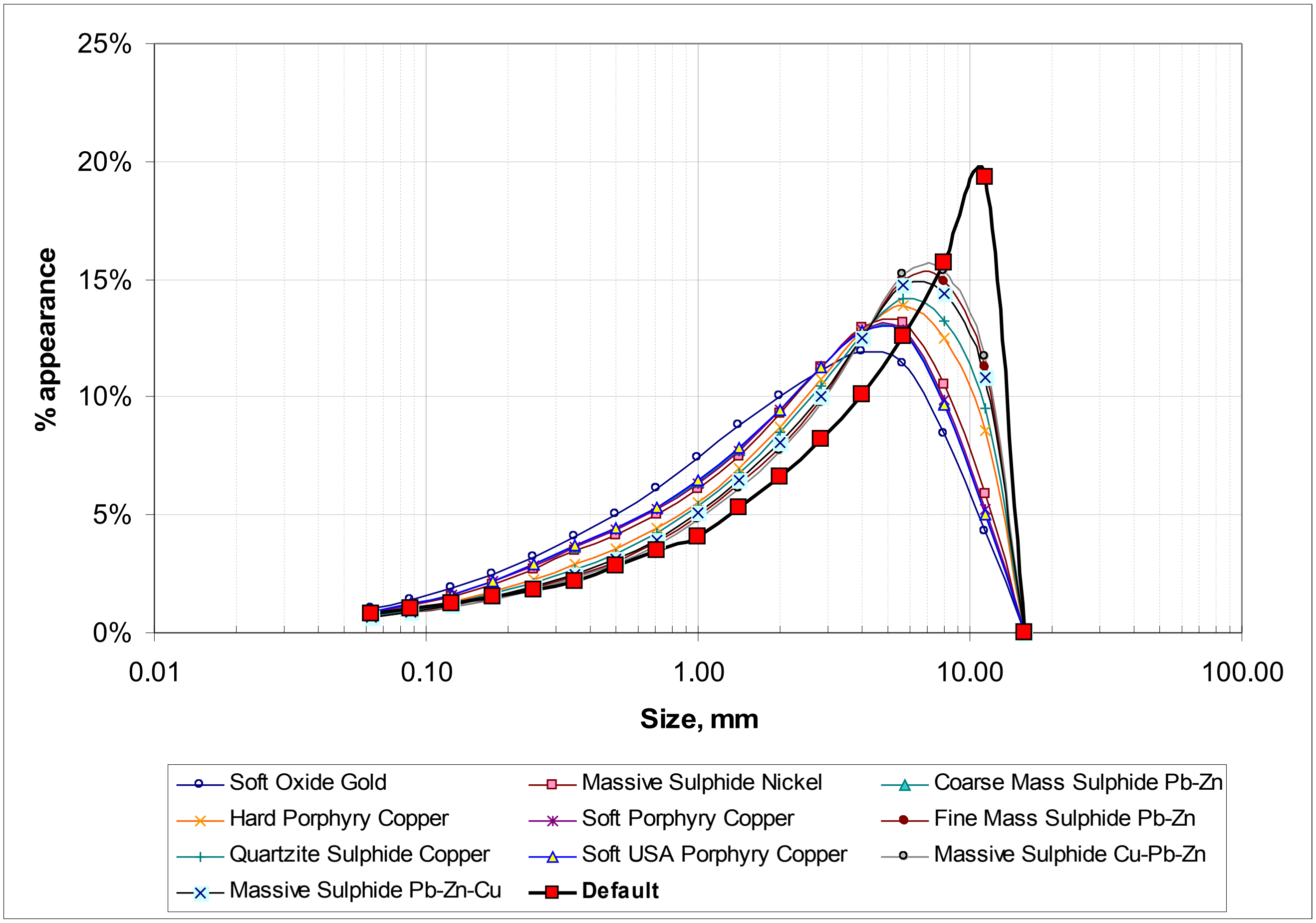

Figure 1: Ball Mill Appearance Functions

Once fitted, the appearance matrix ***A***, the breakage rates *r* and the discharge rate *d* along with a specified feed *f* may be used to estimate any ball mill product *p*. Note that *d* is a function of the geometry of the mill being simulated and both ***A*** and *r* are properties of the ore and do not vary with mill geometry. Other factors reflecting ball sizes, mill speed, etc are also applied during scale up of pilot plant results to a commercial machine.

To achieve the best results with this fitting, the appearance matrix must be determined with a modified drop weight test for ball milling. Using the JKSimMet default value will underestimate the amount of grinding that the mill is capable of.

Power draw estimate

JK SimMet uses a two-step approach to calculating ball mill power. The first step is to determine the amount of power that an ore needs to grind to a target size, then the second step determines the amount of power a particular mill (and circuit) imparts to the ore. By iteration, the mill size is determined such that it provides enough energy to break the ore to the desired product size.

Power draw, Step 1

The power required by the ore to achieve a desired size is estimated using the standard Bond ball mill work index from a testwork program. This work index is used much as described in the original Bond method except that the feed rate and F_{80} to the Bond calculation is adjusted to compensate for a SAG mill creating more fines than an equivalent rod mill circuit. The original Bond work assumed the feed to the ball mill circuit was rod mill product.

The adjustment is done using a "phantom cyclone" calculation where a portion of the final P_{80} sized material from the SAG mill is mathematically bypassed to the finished product, and is not used as part of the power calculation. The quantity of material that bypasses the ball mill power calculation depends on the method used to simulate the phantom cyclone, but in general, the ball mill power calculation will see a smaller flow of coarser F_{80} than than the real ball mill circuit will see in practise.

The methods published by Arterburn of Krebs Cyclones, and Plitt of the University of Alberta are suitable for conducting a phantom cyclone calculation. The Arterburn method is available here:
http://www.krebs.com/documents/83_sizing_select_cyclones.pdf

Power draw, Step 2

The power consumed by a ball mill is described in equation 9.16 in the JKMRC text. The power is a function of mill diameter, volume fraction filled with balls, fraction of critical speed, ball size, and the tonnage of balls in the mill. These parameters are adjusted to provide a mill geometry and charge suitable to impart enough power to the ore to satisfy the Bond and phantom cyclone power demand. Equation 9.16 is rather long and is not repeated in this text.

Power draw, Pilot Plant

Where a pilot plant or operating plant is being simulated, the effect of the phantom cyclone is calibrated to the circuit being simulated. The method published by Barratt in the SAG 1989 conference proceedings outlines use of the Arterburn model to adjust the results of a pilot plant program that used spiral classifiers to derive power draw estimates for a cyclone-based industrial scale circuit. Similar methods are used when running JK SimMet to correct the pilot plant secondary mill power to compensate for the unnatural ball mill feed when pilot plants use DSM screens or spiral classifiers instead of hydrocyclones.

References

1. *Mineral Comminution Circuits Their Operation and Optimisation*, 1996, Julius Kruttschnitt Mineral Research Centre, Australia
   ISBN: 0 646 28861X
2. *The Sizing and Section of Hydrocyclones*, (undated) Richard Arterburn, Krebs Engineers, USA
   http://www.krebs.com/documents/83_sizing_select_cyclones.pdf
3. *An Update on Testing, Scale-up and Sizing Equipment for Autogenous and Semi-Autogenous Grinding Circuits*, 1989, Derek Barratt, SAG 1989 conference, Vancouver, Canada
   ISBN: 0 88865 355 7