Grinding control strategy on the conventional milling circuit of Palabora Mining Company

by B.J. du Plessis*

Synopsis

Automation of the conventional grinding circuits of Palabora Mining Company (PMC) required that adequate instrumentation and a control system had to be put in place, after which extensive testing had to be done to evaluate different grinding control strategies. The objective was either to optimize the particle size from the grinding circuit, or to increase milling circuit throughput while maintaining particle size at existing levels.

Prior to automation of the process as described below the circuits were controlled manually. No on-line information on cyclone feed densities, cyclone feed flow or cyclone overflow particle size was available. This type of control relied heavily on interpretation of the process parameters by the operator and on his ability to make informed decisions on what the set points should be.

An integral component of the automation process was the installation of a SCADA package (SysCad SDX) for implementing the on-line control strategy.

A self-correcting model for prediction of cyclone particle size was developed and implemented on the SDX. The model is calibrated using values from the particle size analysers while they are operational. If the particle size analysers choke or fail for any reason, the model continues to provide a good estimate of the particle size. This technique ensures that a continuous particle size indication is available compared to the intermittent reading from the instrument. The continuous signal allows particle size to be used as a process variable for control purposes.

A strategy was developed and implemented which allows for the production of a controlled grind size from the conventional milling circuit to the flotation circuit. The grinding control strategy allows for the control of particle size from the individual cyclone overflows. This strategy allows the operator of the process to increase or decrease production rate by specifying a coarser or finer grind size required for flotation.

Introduction

There are six parallel conventional milling circuits at Palabora Mining Company. Each milling circuit consists of a rod mill followed by a ball mill in series. Crusher product (-9 mm) is fed to the rod mill, and the water is fed in ratio to the ore feed mass. The rod mill discharge is pumped, without any further water addition, to the first ball mill. The ball mill discharges to a sump where water is added before the slurry is pumped to the first cyclone (Cylcone 1). See Figure 1 for a schematic of the process flow.

The slurry stream is classified at Cyclone 1 with the overflow going to the flotation circuit. Cyclone 1 underflow constitutes the fresh feed to the second milling circuit that runs in closed circuit with its own cyclone (Cyclone 2). Ball mill 2 discharges to a sump where water is added before the slurry is pumped to Cyclone 2. Cyclone 2 overflow gravitates to a distributor and is combined with Cyclone 1 overflow before gravitating to the flotation circuit. Cyclone 2 underflow circulates back to Ball Mill 2.

SCADA system

The consulting company for this project developed a SCADA system, called SDX. This system is capable of transferring the process data from the DCS network into a standard PC. Certain pre-selected values are stored in a database residing on the PC. A part of the SDX software is an optimizing environment where calculations with the available process data from both the DCS and the database can be performed. Figure 2 shows the hierarchy of the control hardware.

Particle size prediction

The particle size analysers (PSAs) give reliable results when they are on-line. A continuous sample of the cyclone overflow has to be taken and presented to the instrument. The PSAs tend however to be off-line for a considerable

* *Department of Chemical Engineering, University of Pretoria, Pretoria University.*

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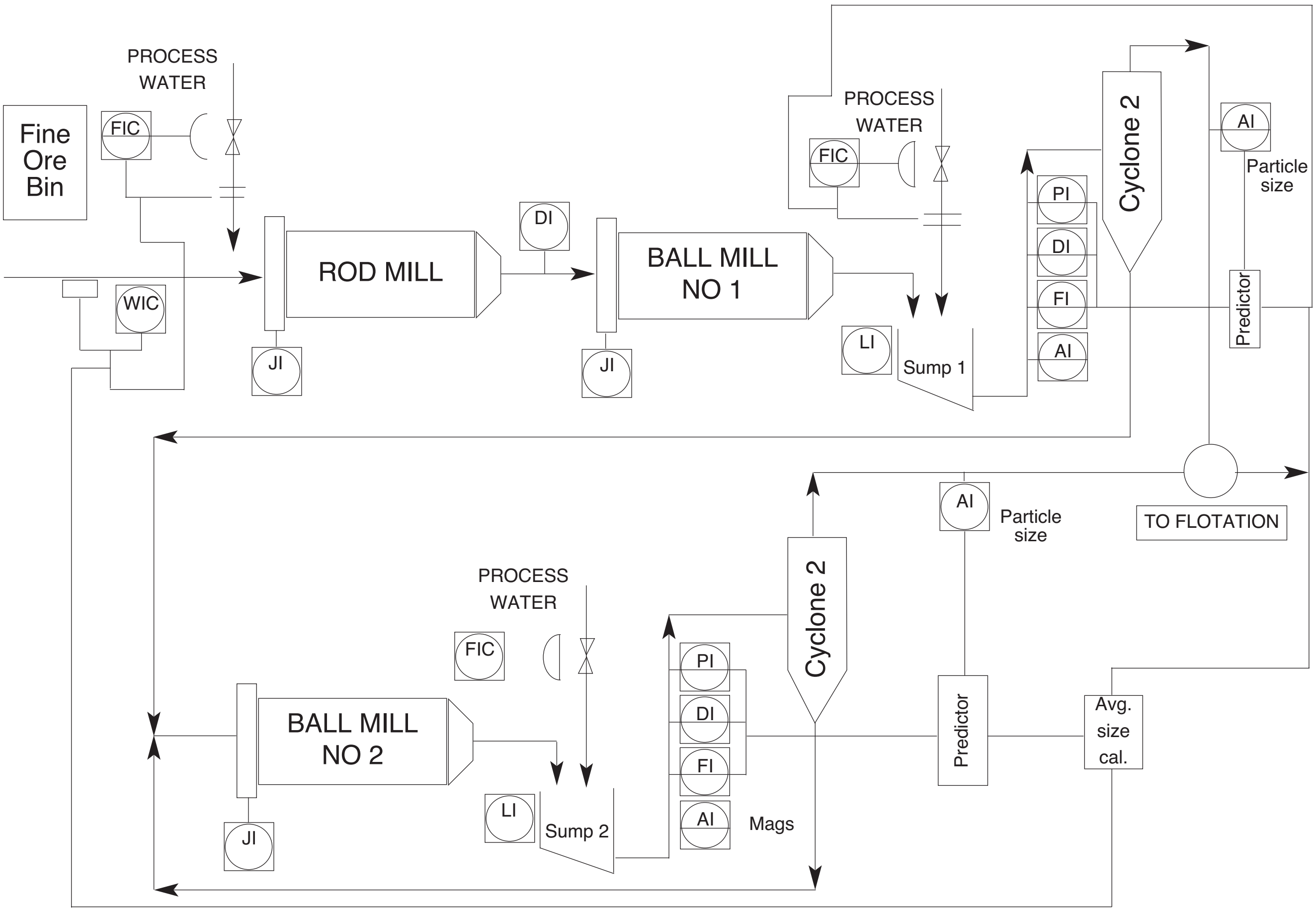

Figure 1—Schematic of milling circuit

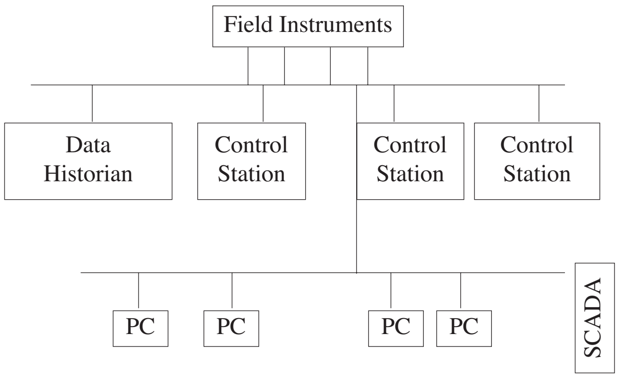

Figure 2—Schematic of the control system

time during the day because of chokes or other malfunctioning of the instruments. An error message is given and an operator then attends to the instrument to rectify the problem.

If the value from the particle size analyser is not available, this measurement cannot be used in a control loop. To overcome this problem a technique to predict the particle size from other on-line measurements was developed.

From work done by other researchers[1,2] the cut size of a cyclone is a function of the slurry feed density, volumetric flow rate and pressure drop over the cyclone. An empirical model using the variables mentioned above was obtained using data collected by the data historian.

$$\% + 300 = Gain * \left(k_1 F^x + k_2 P^y\right) * \left(\frac{k_3 - \dfrac{D}{2.5}}{k_3}\right)^z \quad [1]$$

Where
- %+300 = particle size in cyclone overflow (μm)
- F = volumetric flow rate (m^3/hr)
- P = cyclone pressure drop (kPa)
- D = slurry feed density (kg/m^3)
- k_i, x,y,z = constants
- Gain = constant

All the constants, except the gain are determined off-line using historical values. If the values from the PSAs are available, predicted and actual values can be compared. A linear regression technique is then used to calculate a new gain value every 5 minutes.

A typical situation where a PSA's actual value was lost at about 13:00 is shown in Figure 3. The predicted value was still calculated, and when the signal from the particle size analyser was recovered at about 13:55 the predicted value was still in close agreement with the actual value. The predicted value can therefore be used in a control loop on a

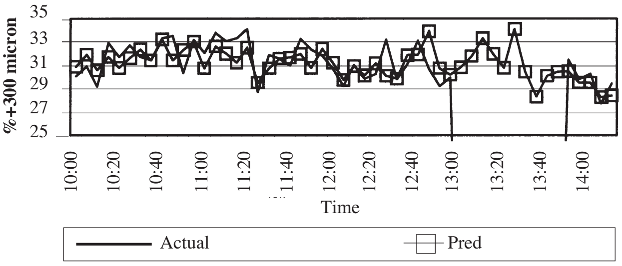

Figure 3—Particle size prediction

continuous basis, whereas the actual value would create problems if used in a feedback control loop.

Average particle size calculation

The particle size of the combined feed to flotation is not measured. A calculation using the particle sizes from Cyclone 1 and 2 overflow and a mass balance split for the two cyclones is used to predict the total particle size to flotation. To calculate the mass split from the two cyclones, an energy balance for the two pump circuits is used. From the energy balance, the measurements that are available are retained, and from that Equations 2 to 5 are developed.

$$Total\ Energy = (Pwr1 * D1) + (Pwr2 * D2) \quad [2]$$

$$Mass\ 1 = Pwr1 * D1 / \text{Total Energy} \quad [3]$$

$$Mass\ 2 = Pwr2 * D2 / \text{Total Energy} \quad [4]$$

$$Average\ size = \frac{Size\ 1 * Mass\ 1 + Size\ 2 * Mass\ 2}{Mass\ 1 + Mass\ 2} \quad [5]$$

Where *Pwri* = power consumption by the *i* th cyclone feed pump (kWh)
Di = cyclone *i* feed density (t/m^3)
Size i = cyclone *i* overflow particle size (prediction) (%+300 μm)
Total energy = an indication of the energy needed to pump material to both cyclones (kWh)
Mass *i* = an empirical measure of the mass from cyclone *i*

Control strategy

The aim of the control strategy is to minimize particle size to flotation for a certain ore feed rate, or alternatively to maximize ore feed rate for a specific required particle size. The control strategy is shown in Figure 1.

The main parameter influencing particle size from the circuit is ore feed rate. Although other factors like water addition, grinding media loading, etc. play a minor role, it was assumed that these in-circuit parameters remain constant for purposes of the control strategy.

Water addition at Cyclone 1 is used to control particle size of the overflow stream of this circuit. In essence this only determines the mass cut to overflow and underflow. With a finer particle size in the overflow, there is thus less material in the overflow. This implies more material in the underflow, which is the fresh feed to the second ball mill.

If circulating load in the second ball mill is kept constant, any variation in the fresh feed will ultimately be reflected in the product particle size of Cyclone 2. Water addition to Cyclone 1 feed sump therefore not only controls the Cyclone 1 product particle size, but ultimately also Cyclone 2 product particle size.

Size ratio control

A new variable, called the particle size ratio was defined as follows:

$$Particle\ Size\ Ratio = \frac{PSA\ 2}{PSA\ 1} \quad [6]$$

where *PSA* 2 = Cyclone 2 particle size
PSA 1 = Cyclone 1 particle size.

The desired ratio of particle sizes is specified, and water addition at Cyclone 1 sump would attempt to control this ratio through a cascade loop. For example if the ratio is specified as 2, and Cyclone 2 particle size is 30 %+ 300 μm, the control loop will attempt to add water to Cyclone 1 sump to achieve a particle size of 15%+ 300 μm.

If the hardness of the ore increases, the particle size in the mill discharge from ball mill 1 will increase. With the same water addition to sump 1 the particle size of Cyclone 1 overflow will increase. This will decrease the ratio, and hence the control loop will add more water to keep the ratio constant. However, the amount of slurry reporting as fresh feed to the second milling circuit will increase.

With the increase in feed material to the second milling circuit, and provided the circulating load stays constant, the particle size from Cyclone 2 will increase. The increase in Cyclone 2 particle size will increase the ratio, and hence water addition to sump 1 will decrease to increase Cyclone 1 particle size and keep the ratio constant.

Figure 4 shows results from a step test done on one of the conventional milling circuits. The particle size ratio set point was varied from 1.0 to 1.4 up to 1.8 and back to 1.2. The response of the individual particle sizes can be observed.

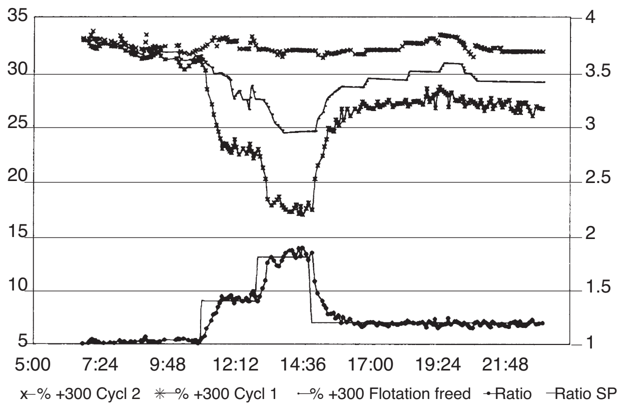

Figure 4—Size ratio control

With the increase in ratio set point, a decrease in Cyclone 1 particle size is required. This control loop will increase the water to the sump to cause a decrease in cyclone overflow particle size.

Circulating load control

The only manipulated variable available in the closed milling circuit (ball mill 2) is the cyclone dilution water flow rate. Attempts to use this for density control were not successful. Because of the high magnetite concentration of the ore it was found that the actual density exceeded the required density, causing the density control loop to become unstable. If the operator did not intervene at this stage, the dilution water to cyclone would close completely. A similar phenomenon was experienced when water addition was used to control volumetric flow rate.

A straightforward sump level control using the cyclone dilution as shown in Figure 1 solved the problem. Analysing data from this control strategy indicated that the volume of material in the closed circuit stayed fairly constant over a wide range of operating conditions.

Average grind size control

The SDX SCADA system is used to calculate an average particle size to flotation, using the two readings from the particle size analysers. This is used in a cascade loop to control the ore feed rate to the rod mill, as shown in Figure 1.

If, for example, the ore hardness increases, the particle size of both Cyclone 1 and Cyclone 2 will increase and hence the total size to the flotation circuit will increase. The control loop will then decrease the ore feed rate, so as to keep the particle size to flotation constant.

A safety feature has been built into this control loop that allows the operator to specify the maximum ore feed rate to the circuit. The operator can thus specify this maximum, and the control loop set point will not be increased beyond that point.

A case study is presented in Figures 5 and 6. The average particle size set point was at 29%. A maximum ore feed rate of 400 tph was also specified. Using the above control strategy a feed rate exceeding 400 tph can be achieved while maintaining the same specification on particle size. Physical constraints (e.g. pipeline sizes, pump sizes, etc.) however necessitate a maximum ore feed rate of 400 tph.

At about 11:00 the set point for the average size was decreased to 28 %. Immediately thereafter the ore feed rate was lowered to try and achieve this particle size. Figure 5 shows the individual particle sizes, and it can be observed that with the lowering of the average size set point, and a subsequent lowering in the ore feed rate, that the average particle size decreased.

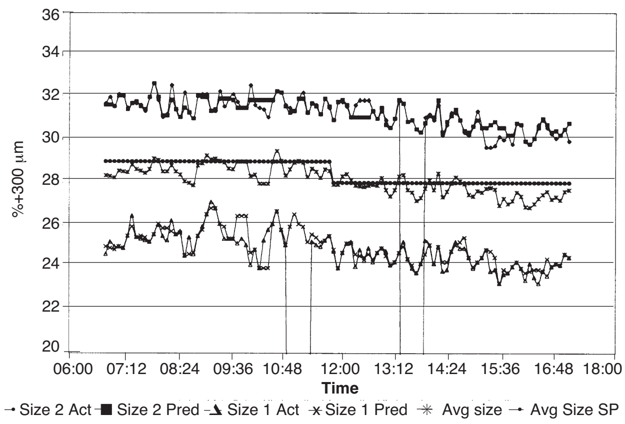

Figure 5—Particle sizes for case study

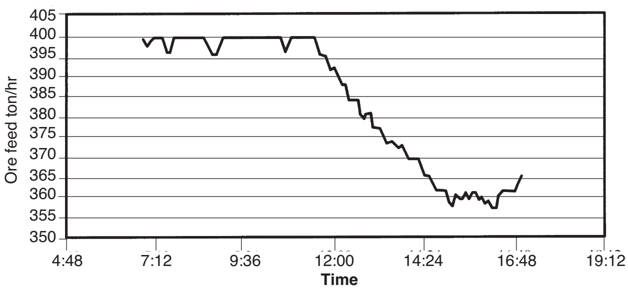

Figure 6—Ore feed rate

Conclusions

The control strategy that was implemented on the conventional milling circuits performed well. The control system proved to be very stable provided the instruments were calibrated regularly.

With the development of the self-correcting particle size predictor, problems associated with the lack of availability of the particle size analysers were eliminated.

With the implementation of the control strategy, an increase of between 2 and 3 per cent in throughput was achieved. Some improvement in recovery (0.9 per cent) was also noticed. It was, however, difficult to prove whether this can be attributed to the control or to mineralogy.

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