OPTIMAL SAG MILL CONTROL USING VIBRATION & DIGITAL SIGNAL PROCESSING TECHNIQUES

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ABSTRACT

Recent developments in low power wireless and Digital Signal Processing (DSP) technologies have given rise to a new system that can monitor vibrations in real-time on the rotating surface of SAG, AG, and Ball mills. Specifically designed for the SAG mill, a new device is presented that digitizes and processes vibration from three key points on the SAG mill. From these three real-time signals, it is possible to measure the volumetric material fill level in the mill and the material flow through the mill. This new information can be used to optimize the feed rate and speed of the mill for increased material throughput, reduced particle size output standard deviation, reduced specific power consumption and to minimize liner damage.

KEYWORDS

SAG, AG, Mill, Vibration, Process, Control, Optimization

INTRODUCTION

The vibration sensor based signals are more responsive and have a greater dynamic range than traditional control signals such as electronic ears, bearing pressure and mill power. The increased response time of these new signals allow for quicker and more accurate control of the mill fill level, thereby increasing the confidence one has in the overall control of the mill. This leads to increased production as more material can be processed through the mill with increased stability/material flow in the overall mill circuit. Trends and results are presented to support these claims as well as a brief guideline on how to use the new technology for optimal mill control.

The basic vibration monitoring system consists of three wide bandwidth custom vibration sensors as shown in Figure 1. Two are mounted on fixed ends of the mill while the third is placed on the mill shell inside an enclosure that houses an RF transmitter. Recharge-able Li batteries are used with the transmitter and the charge duration is typically a minimum of 10 weeks. The fixed sensors can be mounted on either on the actual bearing housing enclosures or other steel/cement mill support structure points. In previous studies, vibration sensor based readings have been shown to be 2.71 times more responsive than the best microphone based system.[1] Spectrum snapshots are taken at installation time to determine the strongest signal location. All sensors and components utilize high strength magnets for quick installation and quick battery swap. An additional sensor called the T-Sync is added on the shell to trigger the transmitter when it has reached the top of the mill. See Figure 2 for a picture of all components magnetically mounted on the mill shell. The outputs from this system are (4) 4-20 mA signals that correspond to an inlet fill level, shell fill level, outlet fill level and liner damage estimation. An Ethernet connection is also required to the main box for real-time ball/liner strike energy plotting and calibration purposes. The equipment used to obtain high resolution vibration signals taken off of the mill shell is very similar to that used in systems previously documented in Australian mining.[2]

INITIAL SENSOR CALIBRATIONS & OUTPUT INFORMATION

Once the electrical signals have been connected to the PLCs and an Ethernet connection has been made to the control room from the main unit, quick calibrations are made to set the signal sensitivities and current operating points for the 4-20mA fill level signals. On these analog signals, 4 mA corresponds to 0% full and 20 mA corresponds to 100% full. Once the mill (and surrounding circuit) has reached stable normal operation, a three minute calibration procedure is run to obtain vibration snapshots for each of the sensors, initially setting their value at 65%. The initial 65% set point for the mill's current operating state allows additional head room for when the mill is loaded above the current operating condition. Once we have these new signals, we can further load the mill and track the increase in the fill levels above the initial 65% set point. After calibration, real-time trends are typically observed for a few hours in the control room and new vibration calibrations and signal sensitivity adjustments can be quickly and easily be made if a fill level trend indicates that an initial fill level set point is too low or too high.

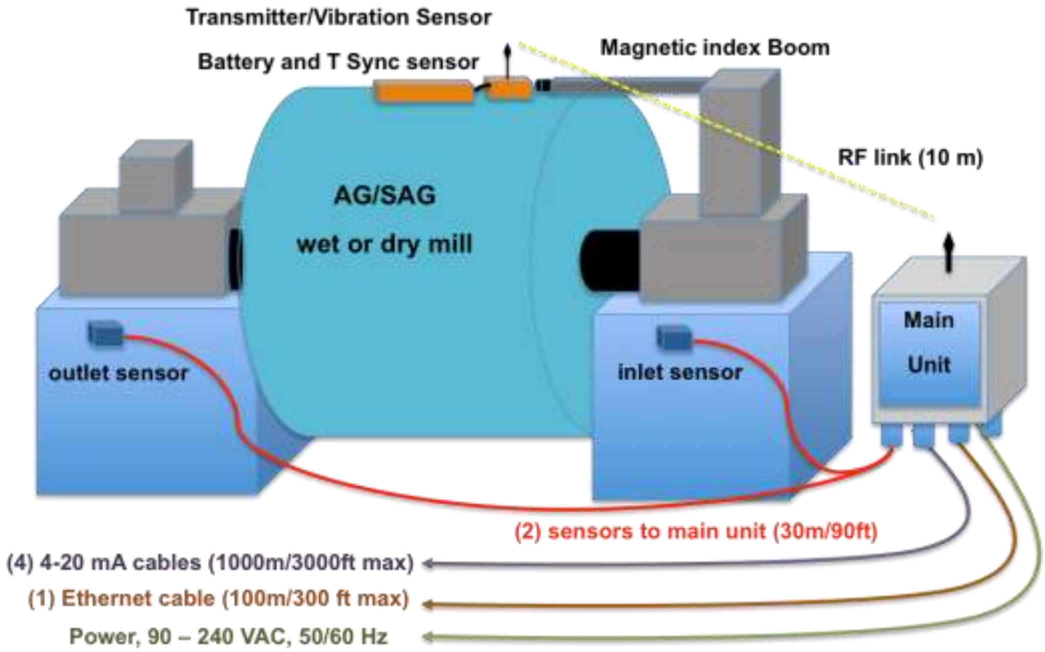

Figure 1 - Vibration System Components

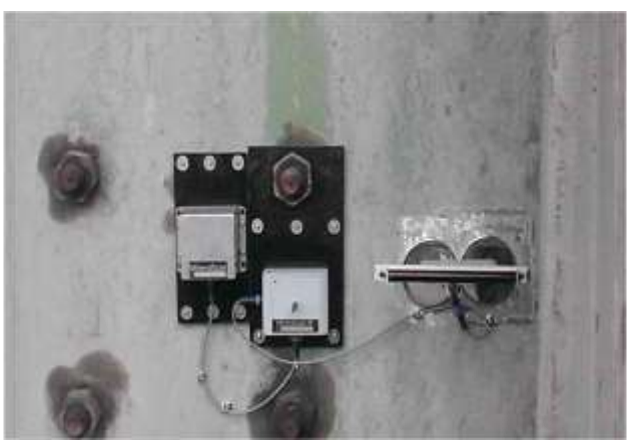

Figure 2 - Shell Mounted Components: Battery, Transmitter, T-Sync (left to right)

In addition to the three fill level (4-20mA output) sensor locations, a polar plot is generated that shows the real-time energy transfer of the balls striking the internal liner. It should be noted that a polar energy plot is updated every mill rotation. See Figure 3 for examples of three screen snapshots of polar plots taken from a copper mine SAG mill.

In the plot, the mill is shown to be rotating in a clock-wise direction with energy plotted increasing towards the center of the plot. The top of the mill/plot corresponds to 0 degrees and the bottom of the plot corresponds to 180 degrees. The red line is an indicator of the shoulder (top left) and toe (lower right) ball trajectory positions in the mill.

In Figure 3, three snapshots were then taken to illustrate three different mill conditions. The left most snapshot was taken when the mill was empty while the middle snapshot was taken when the mill was filled slightly above normal operation. The rightmost snapshot was taken when clay (no hard ore) was being washed through the mill. These ball trajectory energy plots are also consistent with results obtained by previous researchers. [3 4 5]

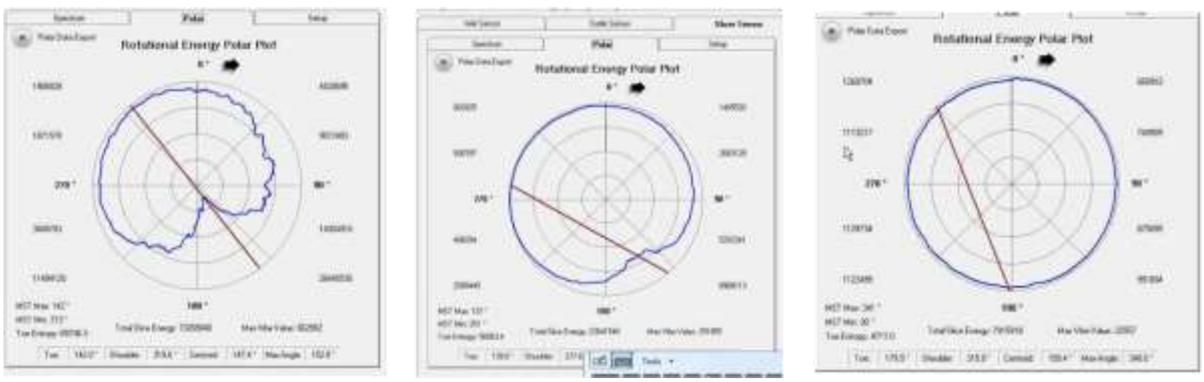

Figure 3 - Polar Plot Energy Examples: Mill Empty, Mill Full, Mill Filled w/Clay (left to right)

VIBRATION CONTROL STRATEGY & RESULTS

The basic goals of SAG mill control using these new signals is to increase and stabilize the throughput of material through the mill to cut specific energy consumption and extend liner life. This is accomplished by performing the following steps:

1. *Polar Plot Analysis* - Ensure that the balls are striking in the proper region of the mill.
2. *Stabilize all Fill Level Signals* - Flatten all fill level signals for 'what goes in/goes out' operation.
3. *Incrementally Increasing the Fill Level Set Point Targets* - Push the throughput to greater levels.
4. *Blockage Detection Using Fill Level Deviations* - Watch for when the signals begin to separate.

Beginning with the *Polar Plot Analysis*, this graphic is used to ensure that the toe position is in an optimal area of grinding and that the mill is not being rotated too quickly. See the three snapshots taken from a large gold mine SAG in Figure 4.

In the leftmost snapshot, the ball trajectory is above 135° (cascade grinding region) with sharp energy peaks occurring due to a 'metal on metal' condition. In the center snapshot the energy is still too great in the shoulder region, left of the toe position where finally, the rightmost snapshot illustrates the ideal energy profile/toe for this particular mill.

In a full mill, we have also repeatedly observed that the ball charge becomes compressed in the shoulder region of the mill due to the increased material in the toe area. We also observe a nice tight energy envelope in the grinding region from 135° to 180° when the mill is significantly filled.

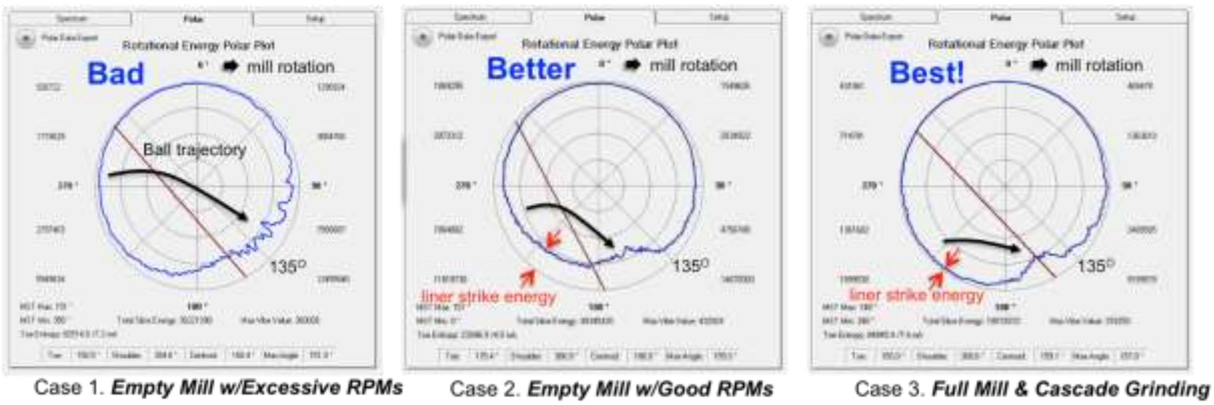

Figure 4 - Mill Conditions: Too Fast, Too Empty, Full Mill (left to right)

After the polar plot is checked to determine if a mill is operating at too high an RPM, the fill levels are monitored. Figure 5 illustrates a trend taken from a SAG mill running under expert system control using bearing pressure as the primary control variable.

In this trend we can observe that the feed is being held constant while the mill speed is being used to reduce the amount of material in the mill with respect to the current bearing pressure reading. The mill can be shown to be filling and emptying significantly according to the three fill levels and it is important to note that the peak of the shell fill level signal (yellow) is several minutes (~5-6) in advance of the peak of the bearing pressure signal (red). Also, for this particular mill, the power signal was very non-responsive (flat) and the client chose not to include it in their trends.

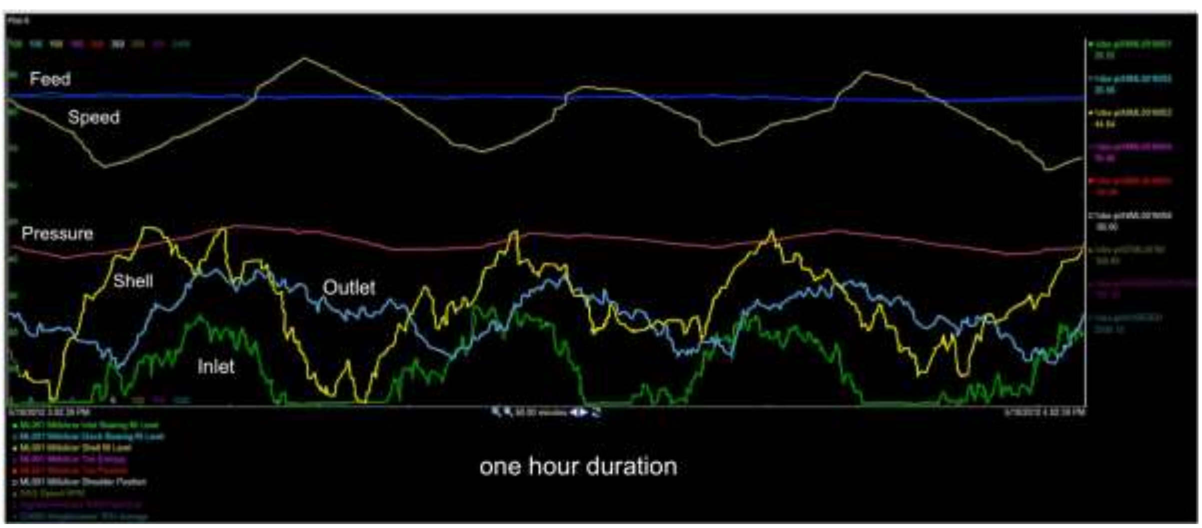

Figure 5 - Expert System Control Using Bearing Pressure

To stabilize all fill levels in Figure 5, a speed was first set that was somewhere between the minimum and maximum values. Then the fill levels were used such that if the three fill level signals began to rise, the speed was very slightly increased. Similarly if the fill levels began to drop, the mill speed was slightly decreased. A speed change was performed every 5 minutes with the actual change in speed being a small amount when compared to the current Mill RPM. The results of this procedure can be observed in Figure 6. Note: During this manual control operation, expert system control was suspended.

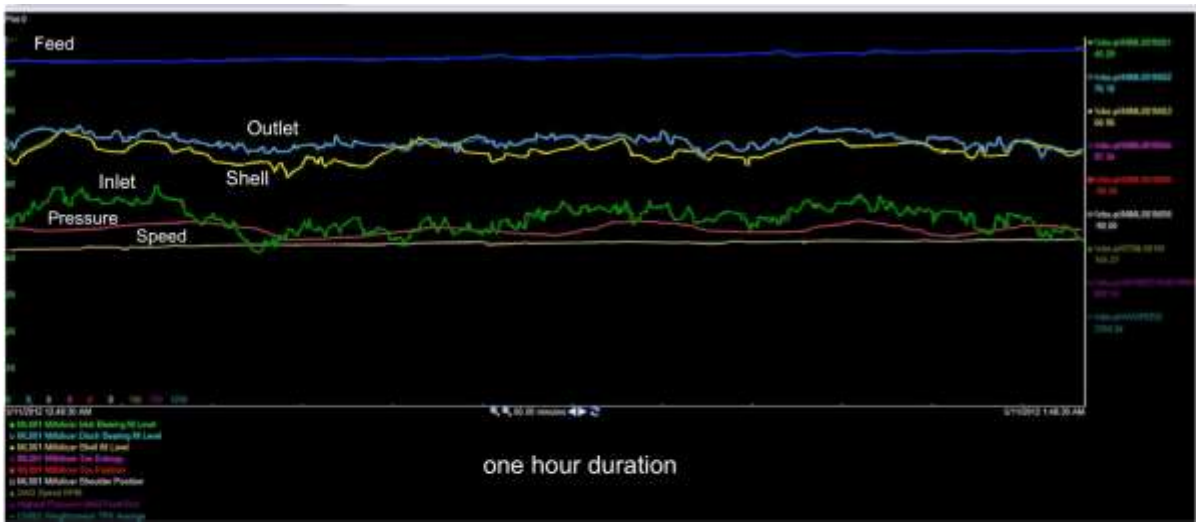

Figure 6 - Manual Control Using Vibration Fill Level Signals (same vertical scale as Figure 5)

When the process variables become stable, we refer to the mill operating in a manner where 'what is going in matches what is going out'. Basically the material in the mill is passing all three sensors in a uniform manner. When this condition occurs, we are now in a position to push the mill to higher volumetric fill levels not possible before these new sensors were available. This is typically done by incrementally increasing the fill level target set points.

To increase the amount of material in the mill we increase the feed. If the aim is to increase material production or reduce power, one can decrease the mill speed to slightly raise the mill fill levels. Once the fill levels increase to their new desired target values, the signals are again used to stabilize the process.

For example, cut speed (to reduce power consumption) to increase the target for the shell signal from 63% to 66%. Then maintain the shell signal at 66% by infrequently making small changes to the mill speed. The goal is always to stabilize the volume of material in the overall mill circuit using this process.

Changes to the target fill level set point are typically not made in less than hour. Changing a set point every two hours or more is more common and allows for one to ensure stable mill operation for an extended period of time. The optimal set point should therefore be determined from the other process parameters i.e. optimal mill power level, maximum bearing pressure, etc. and/or from output material quality measurements. i.e. standard deviation in output particle size. If changes occur in the ore particle size or material hardness over an extended period of operation, the feed rate will certainly need to be adjusted. However the volume of material in the mill should again be kept constant to maintain a constant flow over material through the mill and in the mill circuit.

For example, if a particular hard ore is obtained from the quarry, initially the volume of material in the mill will increase as more material is retained in the mill chamber. This will be observed and tracked in the vibration signals as the volume of material in the mill correlates directly to the amount of vibration produced by the grinding of the material in the mill. Therefore, if particularly hard ore enters the mill, the fill levels will immediately rise and the feed will be immediately cut to maintain the optimal volumetric fill level in the mill. This type of behavior can be observed when pebbles are added to the mill. Fresh feed may need to be cut to maintain the current mill volume (current vibration fill levels). However once the process is stable, we can consider increasing the vibration fill level set points as previous described. Similarly, if softer material is fed to the mill, the feed will need to be increased to maintain the current volumetric fill level.

In Figure 6, the goal was to simply increase production and maintain a higher level of material in the mill to reduce liner wear. The increase in production can be observed when we compare the fill level signals between Figures 5 and 6 where the vertical scales are the same for both trends. There is a significant increase in the fill level signals under vibration control. In Figure 5 the average fill level of all three signals is ~30% while the average fill level in Figure 6 is ~65%. To achieve this, the feed rate was increased by 12% and can be observed by looking at the blue feed signal for both trends.

Upon stabilizing all the process signals, it is unlikely that a blockage will occur at the outlet. However should it happen, it can be quickly detected. Figure 7 is an illustration of this. In this trend the mill was again operating under expert control using bearing pressure as the primary variable.

In the first 10 minutes of the trend, a split can be observed in the inlet (green) and outlet (light blue) fill level signals where a blockage at the discharge end of the mill has occurred. The bearing pressure (red) slowly increases as a result of this and the expert system gradually increases mill speed (brown) until finally ~40 minutes later the speed is brought back down. If you look at where the blockage occurred to where the speed was increased by the expert system, it can be observed to be almost 25 minutes later after the blockage. If the expert system would have sped the mill speed at the point in time where the split in the inlet/outlet fill level signals actually occurred, most likely the under-filling condition at the end of the trend would never have occurred.

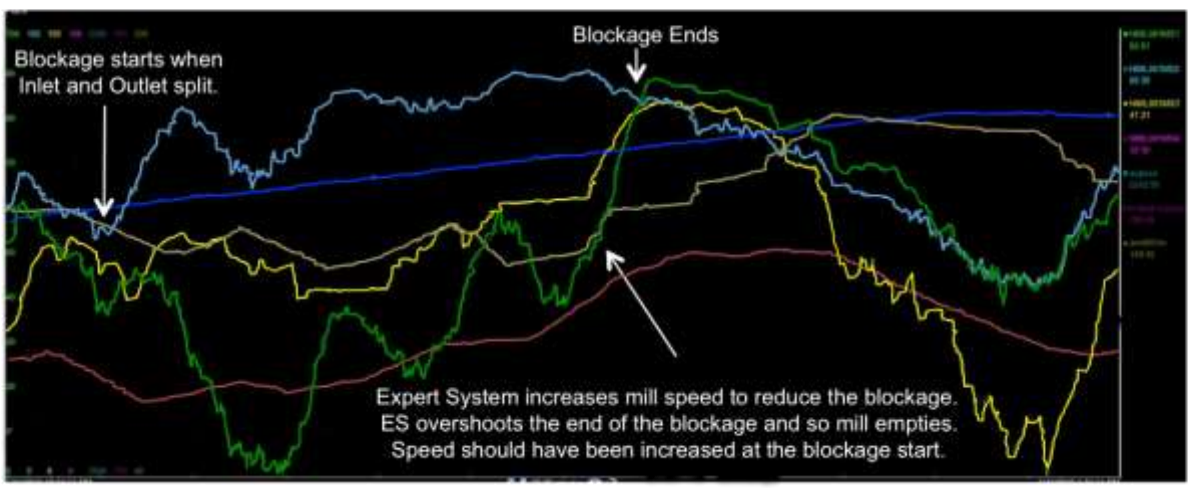

Figure 7 - Expert System Bearing Pressure Control - Blockage - 1 Hour Duration
(Lt. Blue/Outlet, Green/Inlet, Yellow/Shell, Red/Pressure, Tan/Speed, Dark Blue/Feed)

SUMMARY & CONCLUSIONS

The sound emanating from a mill is created by the vibrating surface of the mill that is in turn created by the balls striking the inner liners. By obtaining the vibration signal directly from the mill shell with a wide bandwidth custom sensor, we eliminate all the issues associated with microphones. i.e. maintenance, changes in temperature/humidity, crosstalk from other nearby devices & mills. Additionally, we are able to accurately measure the entire vibration profile as the sensor rotates around the mill (polar plot) to yield the real-time toe/shoulder ball trajectory. This information can be used to observe the actual real-time damage being done to the liners during actual operation.

Example polar plots were presented from installations at Barrick GoldStrike Nevada and Robinson Nevada Mining Company (KGHM). The polar plot is both used to observe the amount of energy of the ball charge striking the liner in the mill and the location of toe. This information can be used in real-time to tune the ideal speed of the mill for optimal grinding and to minimize liner wear. This is presently being performed manually in the first two installations. However in a new installation, Gold Corp Penasquito, we have created a new Liner Damage Level (LDL) signal from the polar plot information and it is being used by the MET expert system to slow down the mill when the LDL signal is too high. i.e. too much ball strike vibration is occurring on the liners in the toe area as observed in the real-time polar. The results of this automated LDL control will be presented at a later date.

Once the ideal speed is achieved, we use the fill level signals to control the mill feed or to make small adjustments in speed. The outlet fill level signal can be used to indicate an overflow condition when it rises quickly with respect to the other signals. Optimal operation is achieved when all three signals (inlet, shell & outlet) are stable and flat with respect to one another.

Since we use fill level signals for real-time control, we use the other mill process variables to determine the ideal expert system set points for the fill levels. For example, if we are operating currently with a set-point of 75% for the shell vibration fill level and we find the output product quality is good and the mill power & bearing pressure are all operating at normal levels then we can increase the set-point for the shell signal to 77%. We then run for several hours at this point and incrementally increase the fill level set-points in this manner. If we observe degradation in output quality or begin to exceed the bearing pressure specifications, the fill level set-points are reduced.

In our early installations, we have observed typical improvements of 5% or more in production and reductions in specific energy using these new control signals.[6] However using these new control signals has been performed manually via operator initiated process changes (manual feed control).

We have plans to work with SGS in the near future at Gold Corp to implement and use the fill level signals for auto-control in the MET expert system. As mentioned earlier, all automated control results will be shown in the future when results are available and approved for publication. It is important to finally note that because this is a very new technology, all installations were initially done on a 'try & buy' trial basis for 45 days; upon completion of the trials, all clients chose to purchase and keep the systems.

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