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Performance enhancement tools for grinding mills

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Operation of large SAG mills requires a change in the conceptual approach to grinding processes. The traditional energy consumption criteria are now enhanced with new criteria derived from the mechanical dynamics of the mill load. This new approach demands instrumentation capable of providing accurate information about the load movement and the ratio of balls and ore inside the mill. This paper discusses two new performance enhancing tools available to meet these needs.

The need for new instruments

Economies of scale play a major role in making new mining projects economically viable and this has led to increased equipment sizes. Although this has been particularly evident in the size of haulage trucks and shovels used in the mining operation, this phenomena has also filtered into the area of minerals processing and into milling in particular. SAG and ball mills have grown in size and there are now many operational mills in the range of 28–40 feet in diameter with installed powers ranging between 8–20 MW. The very high capacity of these mills and the common use of variable speed drives often result in operational problems. These problems are associated with high-energy impacts striking mill liners resulting in poor energy efficiency, as well as the fracture of steel balls, accelerated wear, and even liner breakage. This has given rise to the need for a new range of instruments aimed at providing information to the operator about the load composition and movement within SAG mills.

The concepts for operating SAG mills have been inherited almost entirely from conventional ball mills. However, these mills operated under a constant ball load and at a fixed speed, the slurry load and properties being the main sources of concern. Under these relatively stable conditions, theoretical approaches based on energy amounts required for the grinding process were the rule. Bond developed his Work Index concept as a general property of the ore. Later, a set of parameters S_i and B_{ij} were used for describing grinding kinetics. All these approaches neglect the details of load movement and how energy is actually used inside the mill. For a long time, it has been commonplace to consider a basic process rule that semi-autogenous mills grind by impact, whereas ball mills do so by attrition. As a consequence, SAG mills have been designed and operated to generate a large number of impacts by the falling load, without paying much attention to the place where these impacts are occurring. A second consequence has been that as long as the mill is consuming the expected power, there is little concern about the class of bodies using the supplied energy[1].

Sensing load movement: the Impactmeter* (patent pending)

In recognition of ore variability, many current SAG mills are installed with variable speed drives, capable of operating the mill through a wide and continuous range of speed values. Mill speed and liner profile determine grinding media trajectories, as shown in Figure 1. By increasing mill speed or the steepness of liner attack angle, grinding media may be inadvertently permitted to strike on the mill liners instead of being directed to impact on the mill load (see Figure 2), resulting in wasting large amounts of energy, damaging and breaking mill liners (Figure 3 and Figure 4) and promoting accelerated breakage and degradation of grinding media (Figure 5). With conventional instrumentation, the mill operator has no sense of these effects, thus being unable to take appropriate control measures. Even in the case where the operator is conscious of this phenomenon, he has little or no feedback from instrumentation to check the extent of the effect of his control actions. These circumstances create a need for new instrumentation to sense load movement effects.

The load movement inside of a SAG mill can be monitored through the audible impacts of the falling stream of ore and grinding media with themselves and with the mill liners. The mill noise is a mixture of many different sound sources. The main source is the large number of small shocks between load components during tumbling of the mill load, audible as a continuous stochastic noise. An example of the waveform of this noise may be found in Figure 6, obtained on a 36' diameter mill running at 8 rpm and well filled with mineral. When the minerals hold-up in the mill decreases, the mill noise intensity grows inversely, as shown in Figure 7. This effect is the basis of the 'electric ear' patented by Hardinge to control the mineral feed to ball mills. When the falling stream hits the liners in free fall, high energy impacts appear superimposed over the common mill background noise, as shown in Figure 8. Figure 9 shows the amplitude spectra associated with each sound sample, in relative units. It is easily seen that spectra are not effective tools to differentiate between high- and low-impact operating conditions.

*Impactmeter patent pending in Australia, Canada, Chile, South Africa and USA

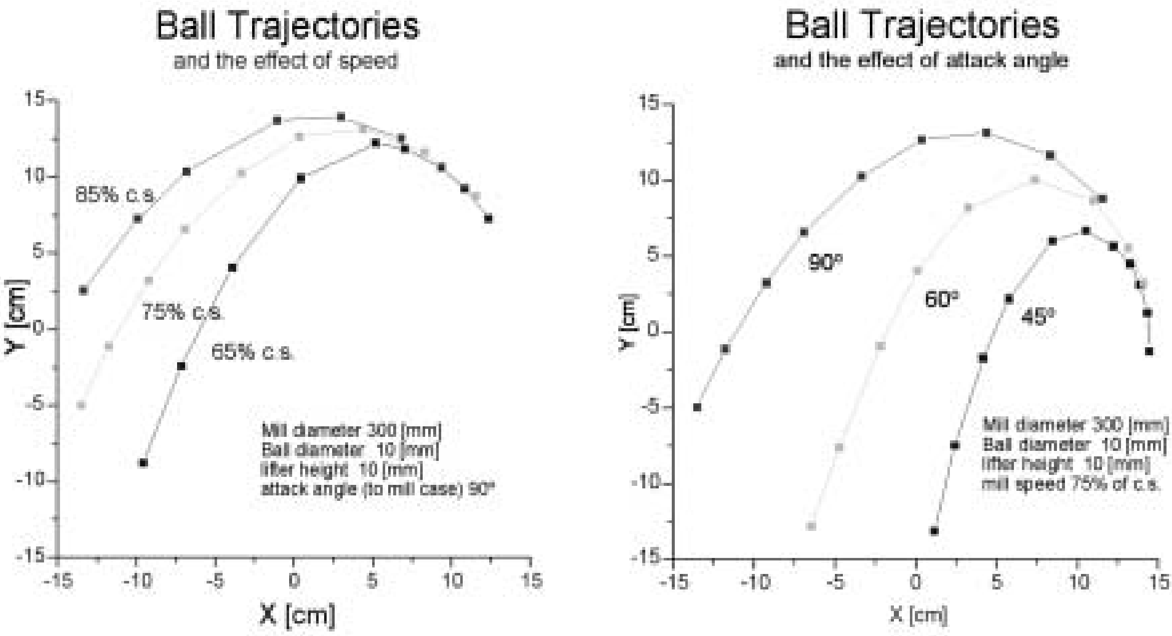

Figure 1. Effect of mill speed and lifter profile on load trajectors

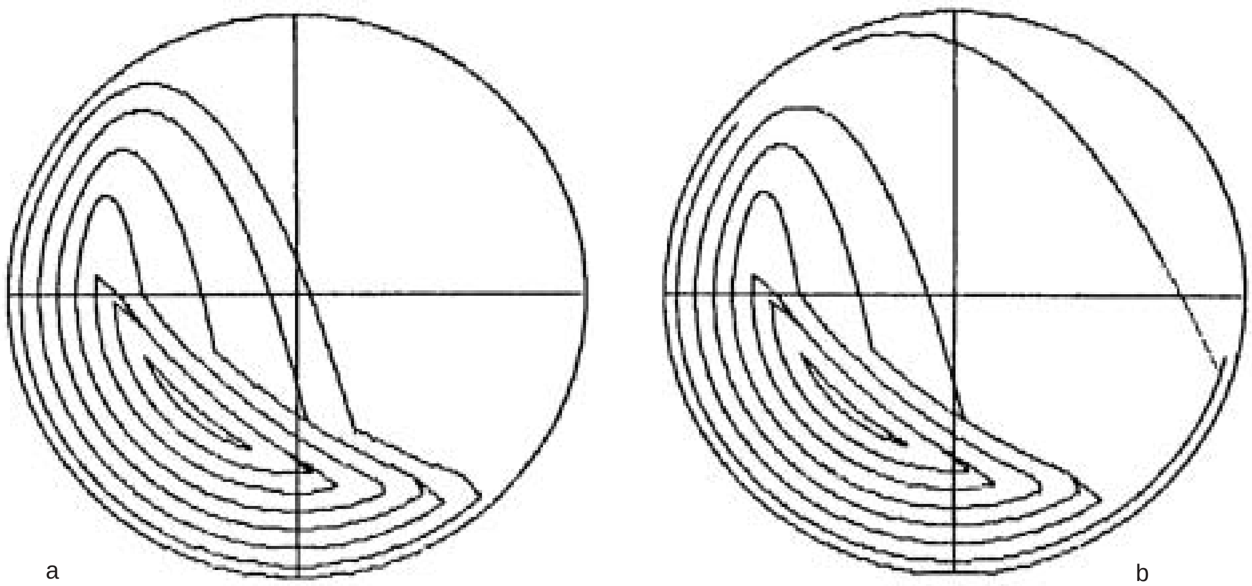

Figure 2. Schematic view of ball trajectories. Load falling onto itself (a) and on the liners (b)

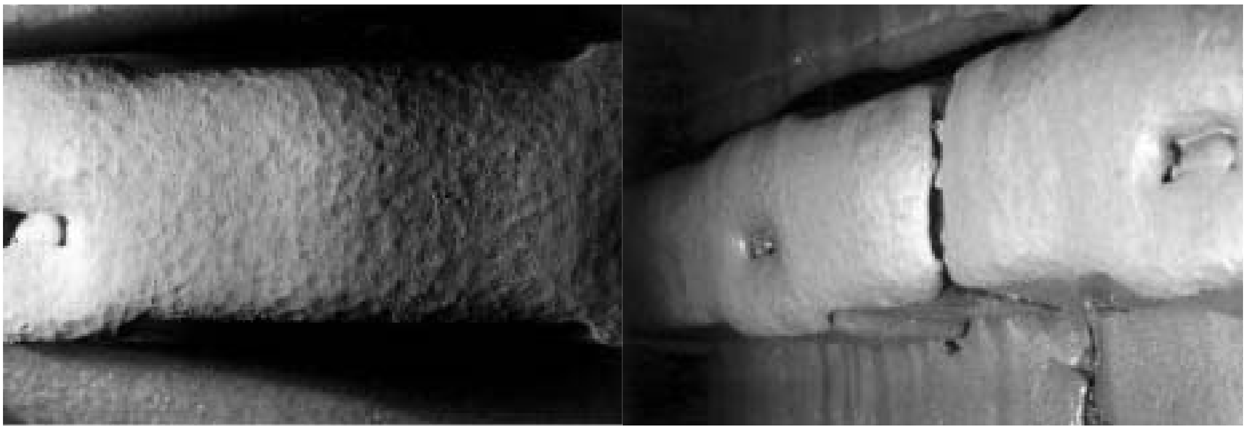

Figure 3. Examples of liner damage under impact

Figure 4. Broken liners

Figure 5. Excessive speed and low mineral hold-up cause extensive ball breakage

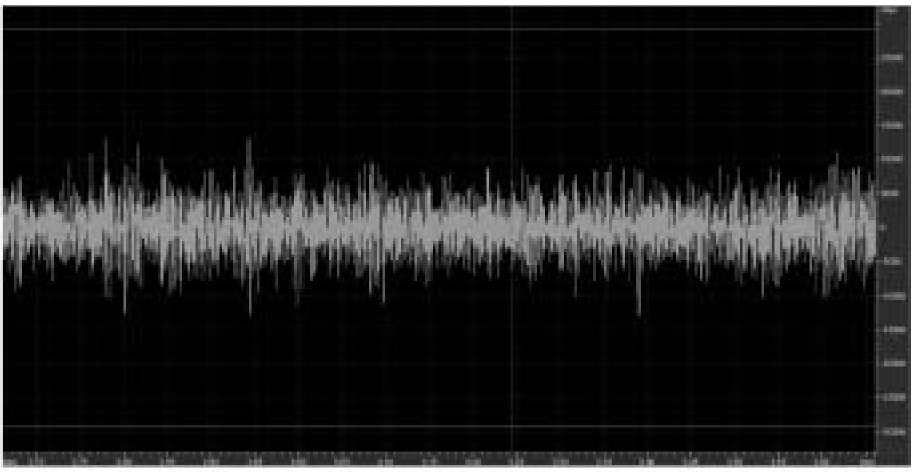

Figure 6. Low-noise, low-impact operating conditions as displayed by CoolEdit software and reflected as sound amplitude over time

By locating microphones near the mill on fixed positions and applying appropriate algorithms online to the microphone signals, impacts on mill liners can be isolated from mill noise, then classified and counted to provide a quantitative measure of their occurrence. The observed distribution is partitioned into two ranges and the counts on each range are defined as 'standard impacts' and 'critical impacts'. Critical impacts comprise mainly direct impacts to the liners, as these show higher acoustical levels. This method of monitoring impacts, together with the specialized hardware and software developed for use with the acoustic sensors, has been referred to in this paper as the Impactmeter[2].

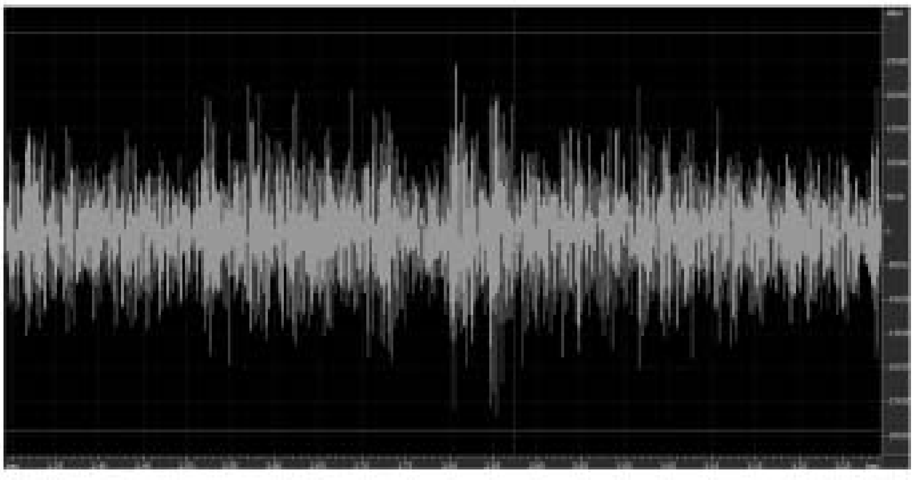

Figure 7. High-noise, associated with a low mineral hold-up condition as displayed by CoolEdit software and reflected as sound amplitude over time

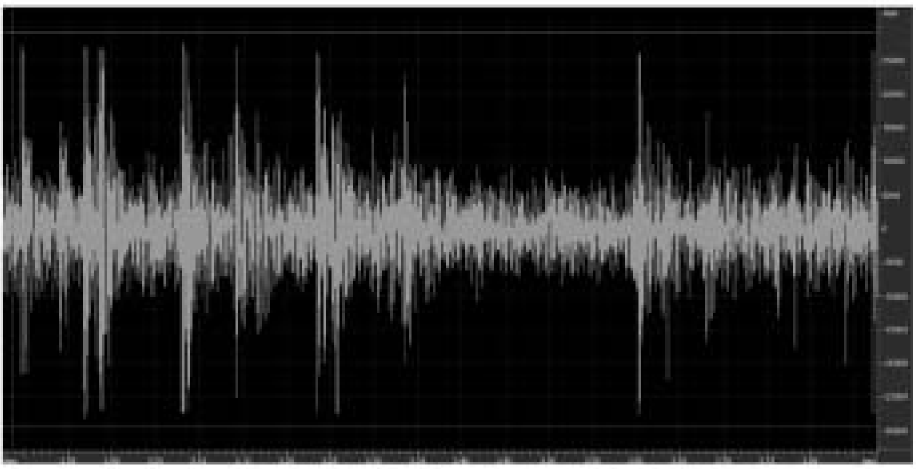

Figure 8. Impacts superimposed over mill noise as displayed by CoolEdit software and reflected as sound amplitude over time

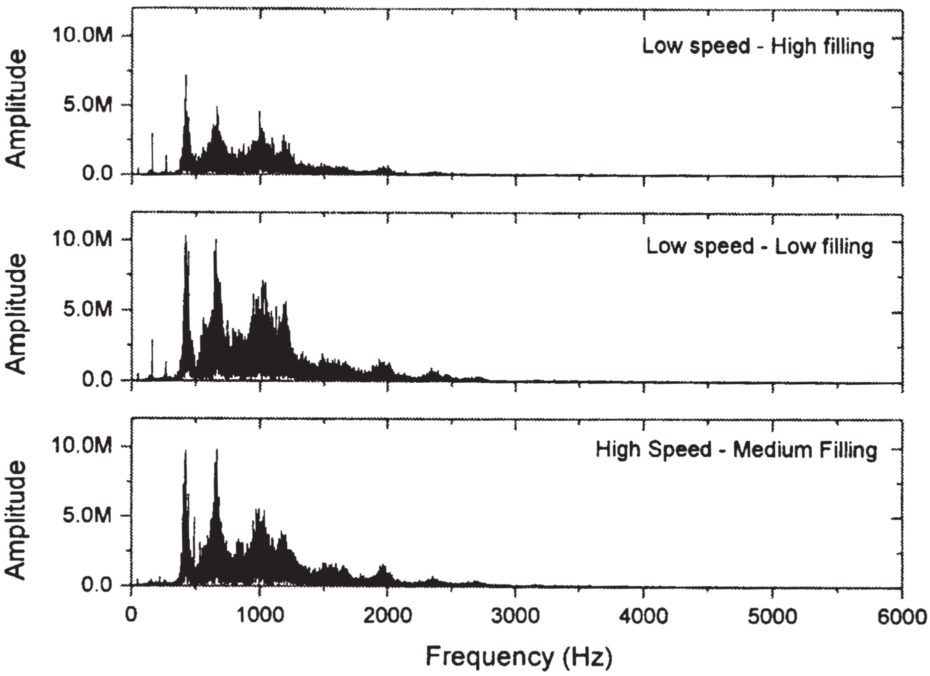

Figure 9. Samples of mill sound spectra, under low- and high- impact conditions

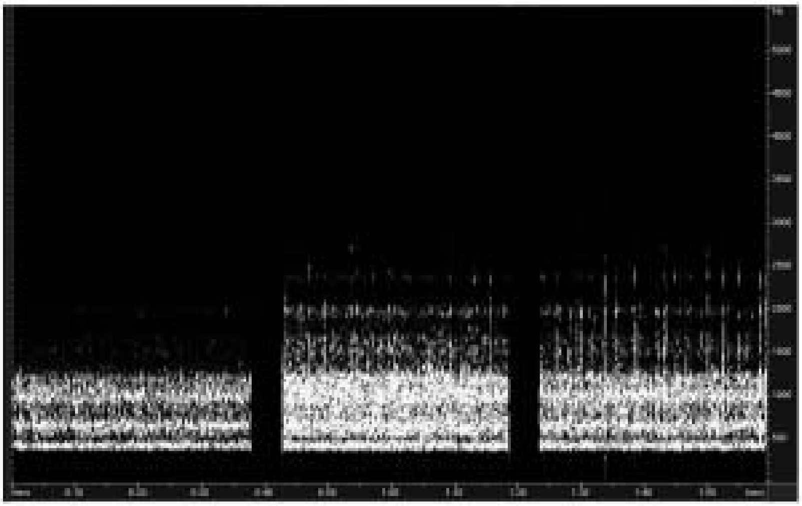

Figure 10. Time evolution of sound spectra for the three sound samples of Figure 6, Figure 7 and Figure 8. Time units are (minute:seconds)

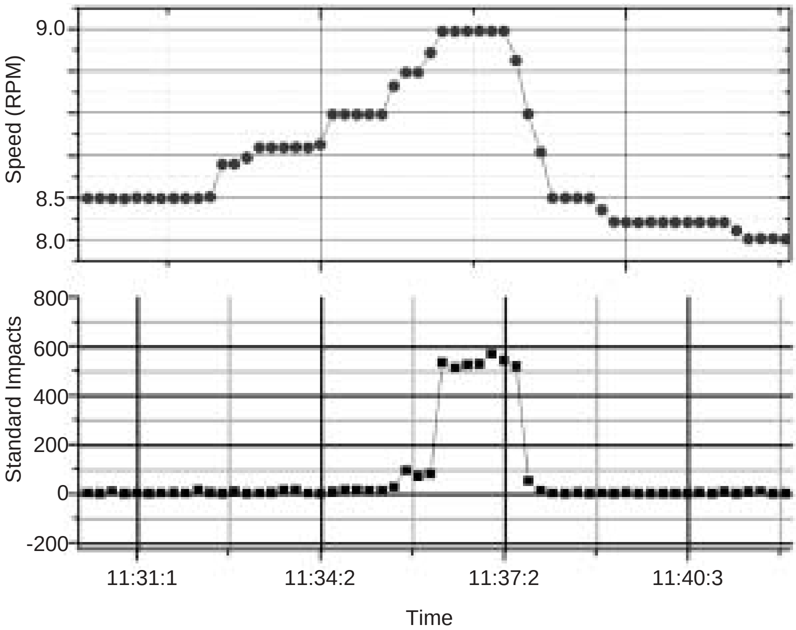

Figure 11. Variation of standard impacts, count with mill speed

The Impactmeter signals provide the information needed for mill control. By maintaining the critical impact rate in a low to nil value, the best instantaneous load movement pattern is obtained, controlled either by a human operator or the automatic control system. The main variable used for acting on impact rate is mill speed. It has a direct effect, is easily controllable, and presents little interference with other variables. Figure 11 shows the dependence of standard impact rate with mill speed. There is a minimum speed to observe impacts. Low mill filling, coarse feed and low solids percentage may also increase the standard impact rate, and even the critical impact rate in extreme cases. The appropriate control action differs in these cases. Low mill filling and solids percentage must be compensated *per se* acting on feed rate and water flow, respectively. The increase of standard impact rate is derived mainly from the lack of cushioning material at the contact points, which has an amplifying role on the whole mill noise. Mill speed can be lowered during the transient time to reduce the impact rate, but it may be a secondary consideration. Coarse feed effect is derived both from lack of fine material for cushioning and from changes in fall trajectories due to the associated higher position of load shoulder. This last effect may be compensated with a slight decrease in mill speed.

The effects and benefits of online controlling of the load falling trajectories may be exemplified with the following data, extracted from a Chilean SAG plant. Operating data comprising a whole week was analysed. The data was classified by tonnage in quartiles, selecting the quartile of highest tonnage for analysis. Figure 12 is a plot of the mill speed and bearing pressure for each point of the high tonnage data set. It may be seen that these points populate over high speed and high bearing pressure, signalling a good mill filling. All process points showing high critical impact rate are shown on the same plot. Most points are situated outside the field of high tonnage conditions. Only at the zone of high speed and medium bearing pressure is

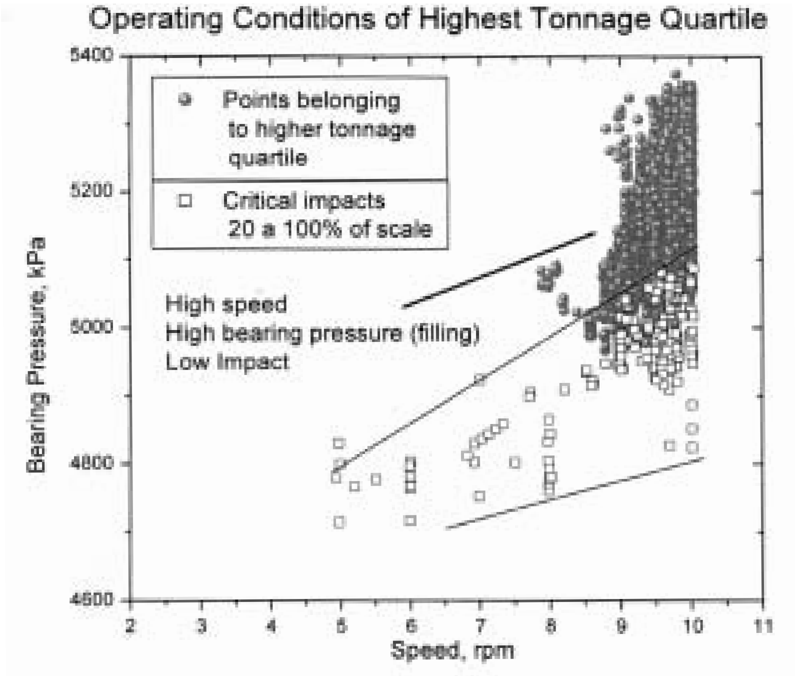

Figure 12. Inverse relationship between high tonnage and high critical impact

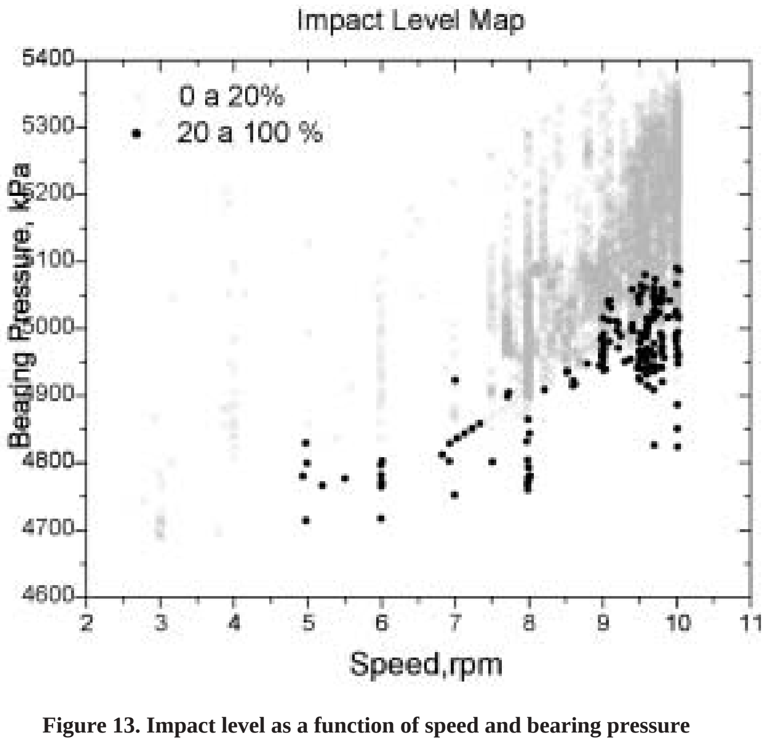

Figure 13. Impact level as a function of speed and bearing pressure

there a degree of correlation of both data sets. By observing Figure 13, there are also low impact points in this zone, due to third variables acting on impact rate. The main benefit of operating under low impact conditions by using the Impactmeter signal is self evident from this data: better tonnage and lower specific energy consumption. Additional benefits related to reduced steel consumption in balls and liners, and the reduced risk of liner breakage are also evident.

Sensing load quality: the SAG Analyzer† (patent pending)

A second operational problem is the uncertainty of the composition of mill load. Data obtained from load cells or bearing pressure simply provide information about the load weight, but do not provide any information about load volume or apparent density. The varying nature of mill charges is such that there can be many combinations of balls, mineral and water having the same weight but comprising differing proportions of these components. This

†SAG analyser patent pending in Australia, Canada, Chile, South Africa and USA

uncertainty may be very misleading for the operator. It is possible that a load composed largely of balls may be interpreted as a ‘very hard ore’ condition, due to the lower tonnage and higher power consumption observed. Also, in spite of efforts to keep the ball level at a constant value, ball breakage or changes in the mineral feed may produce marked variations that may remain hidden to the operator. For these reasons, there is an additional need to know the ball level inside the mill.

The load level and composition by percentage volume of total mill volume may be determined through the use of mill noise (see Figure 14), process data and software based on appropriate algorithms. This method of determining mill load composition, together with the software developed, has been referred to in this paper as the SAG Analyzer[2]. Other authors have reported work in this field[3–10].

The SAG Analyzer performs a two-phase workflow. During the first phase, a microphone located on the mill shell sends acoustic data to a main unit, where the toe and shoulder positions are measured by appropriate algorithms. This data is fed to models, which give a close estimation of the load volume. During the second phase, the ball level is estimated from the load volume just obtained and data extracted from the mill control system. The underlying principle for this estimation is the analysis of the power consumption patterns of the mill with a detailed power model calibrated with plant data. The SAG Analyzer seeks the ball level giving the best fit to a set of current power data. Making use of these two values, the instrument also calculates the instantaneous load density. This information together with specific process variables extracted from the plant control system, is used to generate, online, a screen display showing total volumetric mill filling percentage, ball volumetric filling percentage, ore volumetric filling percentage, total charge apparent density, angular position of charge toe, and angular position of charge shoulder. Mill speed in revolutions per minute, bearing pressure, tonnage throughput and power draw are also reflected on the SAG Analyzer display monitor, as shown on Figure 16.

The main benefit of this new technology is the gain in plant stability. The reduction of uncertainty about ball level does allow better control actions by a better interpretation of the mill behaviour, and assists in more easily identifying the source of concerns. Knowledge of the load volume allows a better management of mill filling, maintaining a higher mean hold-up and facilitates the processing of higher tonnages without the risk of overfilling the mill. An advantage of this specific technology is that it is based on

Figure 14. Sound trace used to find the charge position during a revolution of the mill. The toe is near the highest amplitude points

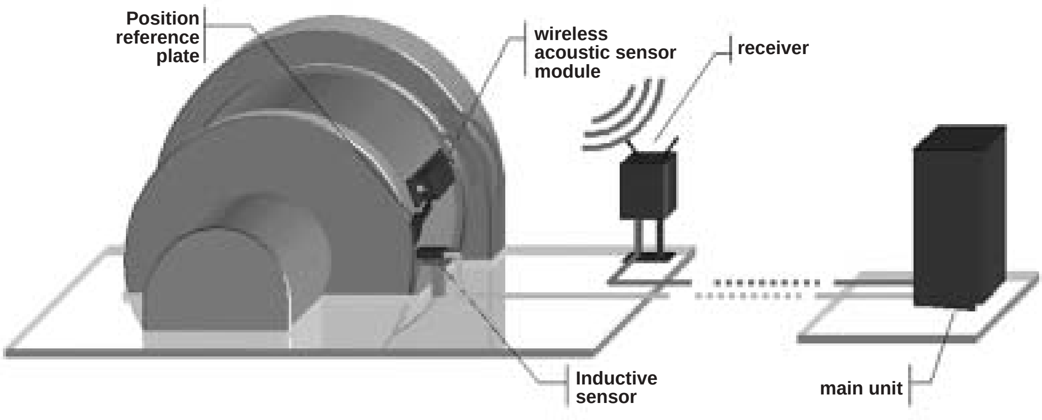

Figure 15. Layout of the microphone and position sensor in the mill

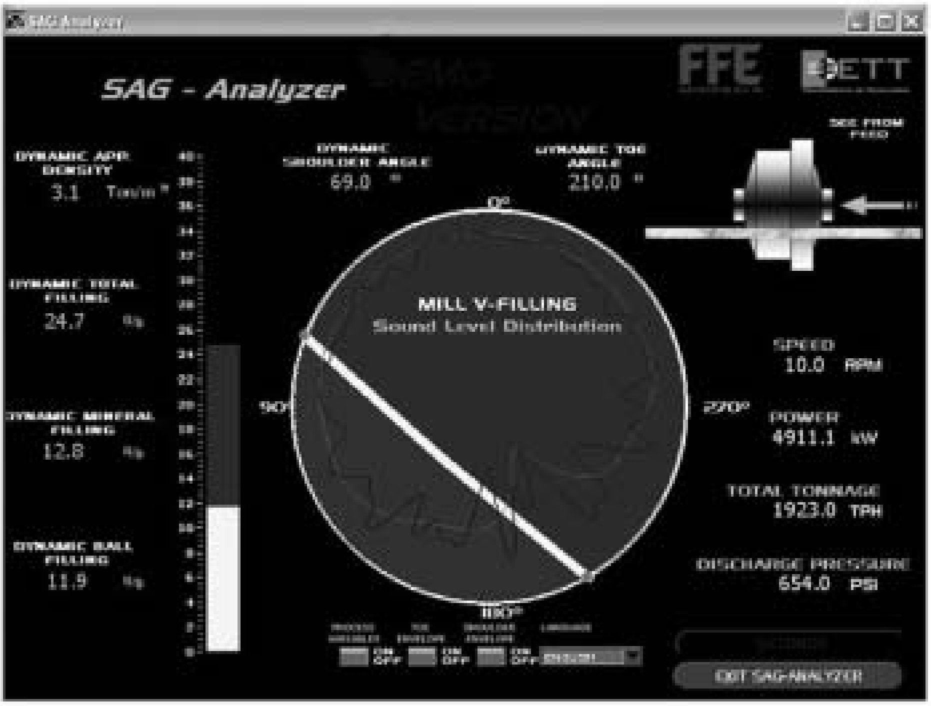

Figure 16. SAG analyser Monitor display**

direct measurement of load toe and shoulder positions, thought to be a reliable source of data to support the system operation and quality of information. At the time of preparing this paper, the technology applied to the SAG Analyzer has only been recently installed and no long-term quantitative studies are readily available to fully evaluate its effect on plant performance.

Conclusion

The use of acoustics in conjunction with appropriate algorithm based software can be used effectively to monitor load movement within a SAG mill. The information provided from these methods can be employed to control mill behaviour and enhance mill performance.

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