

REAL TIME MILL MANAGEMENT TOOL OPTIMISING YOUR MILLING PROCESS AND REDUCING YOUR COST

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ABSTRACT

Ball mills are usually the largest energy consumers within a mineral concentrator. Comminution is responsible for 50% of total mineral processing cost.

In today's global markets suffering from the world crisis, mining groups are trying to optimize mill performances by mainly reducing production costs. Since comminution is concerned with liberating valuable minerals for recovery in the separation process, it is crucial to run the mills at conditions which lead to optimum liberation at competitive throughputs with minimum costs (energy and wear). The equipment availability time is also essential to maximise production and profit.

To reach this key objective, continuous and reliable information about the mill operation is vital. An innovative tool which can deliver information about in-mill dynamics has been developed by Magotteaux. It can provide on-line and accurate information about grinding ball and pulp interactions for timely decision making and actions. This tool could be used on its own or linked to an automatic grinding ball loading system named Magoload®. Therefore, by using direct measurement, the ball load can be kept at an optimal level.

This article describes the Sensomag® and presents some of the major improvements that can be achieved with it.

Key words: Comminution, Cost reduction, Process optimization, Process instrumentation, On-line analysis.

INTRODUCTION

The performance of tumbling mills is sensitive to the volumetric mill filling which influences grinding media wear rates, throughput, power draw, and product grind size from the circuit. Each of these performance parameters peaks at different filling values. In order to

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continuously optimize mill operation, it is vital to obtain regular measurements of ball load and pulp position inside the mill.

Our primary aim is to help each of our customers to reduce their production cost and to improve the grinding efficiency, thanks to our high value added products and services.

THE CURRENT WAY TO MEASURE THE CHARGE FILLING DEGREE

Crash stops and grind-out

Generally, crash stops are performed to obtain measurement of charge filling and slurry loading. The crash stop involves running the mill under steady state then cutting off all feed streams to the mill whilst it is being stopped. The filling should be measured at least 3 points along the mill axis. Excess of slurry could also be estimated.

To get rid of pulp and rocks in the charge, a mill grind-out (no ore feed) of 10 to 20 minutes is also performed before mill inspection or re-lining. The complete grind out is required to obtain the accurate ball load measurement or the percentage by volume of balls in the mill. This is usually performed soon after a crash stop.

The basic principle is to measure the height “H” from the charge to the shell and the internal mill diameter “D_i”. By calculating the ratio “H/D_i” and using the graph below (figure 1), the charge filling degree in volume could be estimated.

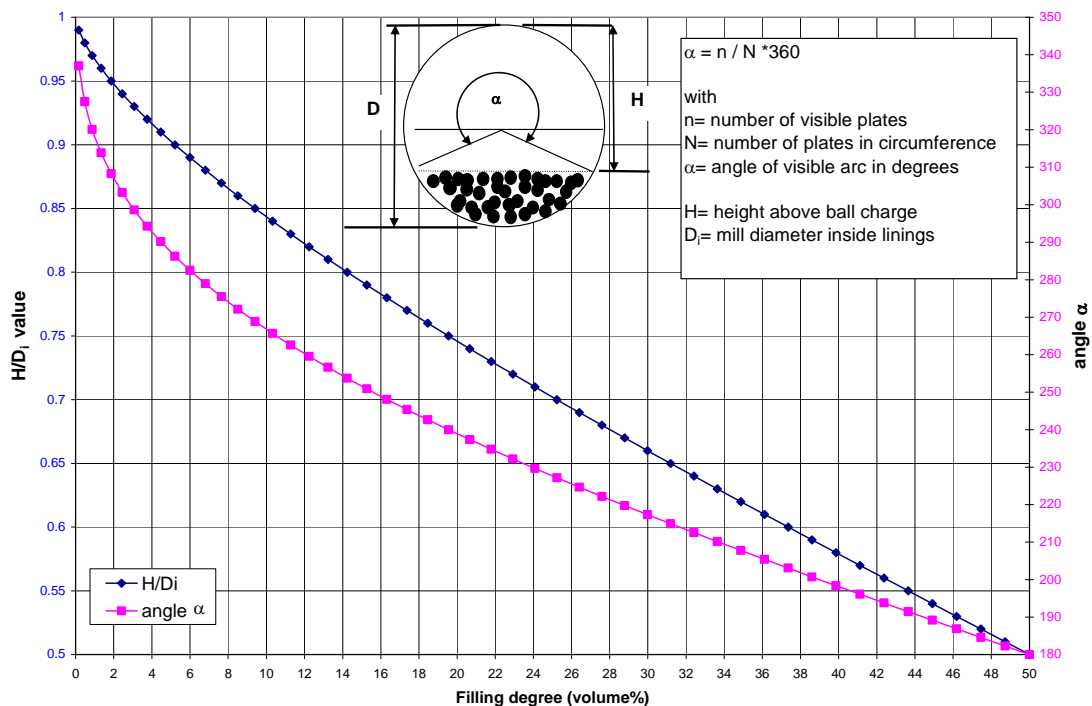


Figure 1: H/D_i and angle α as function of filling degree

Although crash stops and grind-outs provide important information, they have several disadvantages:

- They do not provide the milling internal dynamics which is to say they do not provide the changes in ball and pulp interaction due to operating parameters.
- No data related to liner efficiency can be retrieved. Only wear profile can be measured.
- Production is disrupted for the duration of all the procedure: grind-out, mill stoppage, mill startup and transition period back to steady state.
- Stresses, generated in the ball charge, increase which may result in spalling of balls and blocking the grate discharge.
- Soon after a stop, a mill is a dangerous place to enter for the personnel willing to take measurements or samples.
- Crash stops are difficult to handle. The mill and all feed streams should be stopped simultaneously, failing which slurry could still be pumped out of the mill during a few rotations. The consequence would be inaccurate measurements.

Mill power

Usually, plant operators use mill power readings as an indicator of ball filling degree and, often try to keep it at the maximum level.

It is well known that the mill absorbed power depends on operating parameters other than ball level, such as pulp density, liner configuration, etc.

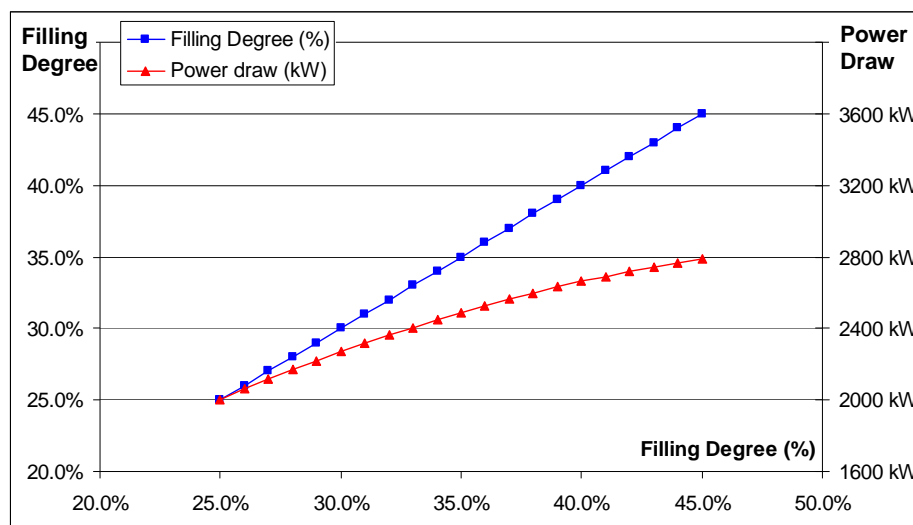


Figure 2: Nonlinear relationship between power draw and filling degree

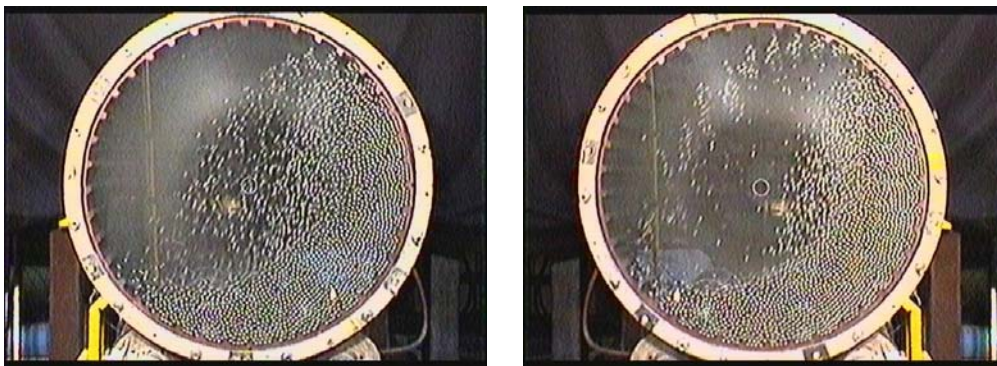
The graph above (figure 2) also shows that, there is no linear relation between mill absorbed power and ball filling degree. As indicated on the graph, a small variation in power could be the result of a significant variation of balls filling degree.

As the ball wear rate depends directly upon the surface of the media charge, small variation in power will lead to an important increase of wear rate. The risk of under-loading or overloading the mill could also be an issue.

A direct measurement of the ball level in the mill, more accurate than power readings, as well as a control of it, is highly important as operating costs are involved.

LOAD ANGLE AS AN INDICATOR OF MILLING EFFICIENCY ?

Toe and shoulder angles of the charge are always used for liner design purpose. Many simulation tools exist to obtain the necessary information about media trajectories. Data are basically used to avoid the risk of liner and ball damage by projecting balls directly on to the shell liner. The picture below (figure 3), on the right, illustrates this issue. Obviously, a good liner design and right operating conditions such as mill speed or balls filling degree, should limit the risk of projection.



Soft (30°) attack angle; 75% CS; J=30% Aggressive (5°) attack angle; 75% CS; J=30%

Figure 3: Lab scale test with low lifting angle (left) and high lifting angle (right)

The purpose of this paper is to go further and to explore issue related to grinding efficiency and costs. There is probably more outcome to be expected from media angle than risk of breakage only.

Many authors have highlighted in published papers that, the ore breakage is closely linked to the ball charge motion. It is well known that ball milling efficiency varies during the lifetime of the shell liner. That is to say, the installation of new liners can cause mill performance to either improve or deteriorate. This situation is illustrated below (figure 4) by an industrial example. The ball (magenta) and pulp (blue) signals are plotted over one revolution. The left graph displays the situation before relining. The right graph shows the situation after relining with new and sharp edge lifters. In this particular case, the ball projections on the liners lasted up to 4 months after relining before disappearing due to lifter smoothing.

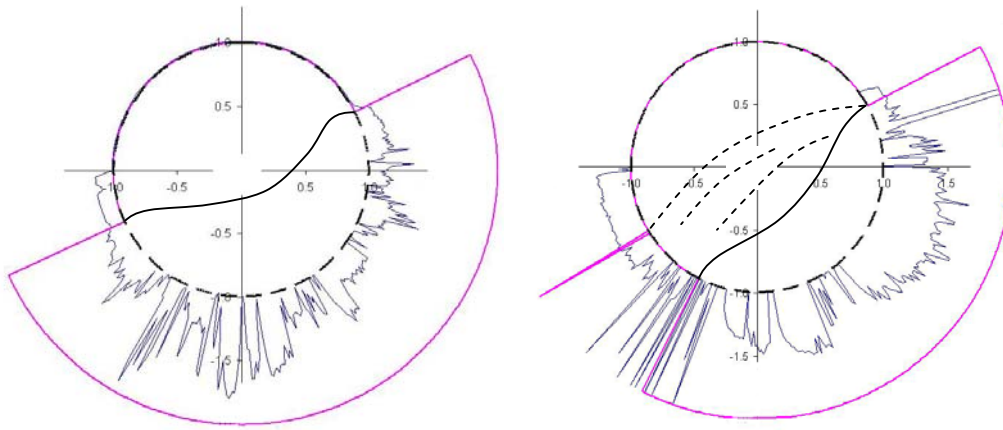


Figure 4a and 4b: One revolution signal plot without projection (a) and with ball projection on liner (b)

Data coming from pilot plant test work has illustrated the influence of the shell lifting effect on the grind for a primary grinding duty. The graph below shows the evolution of the mill discharge product size in relation with the lifting effect of the liners.

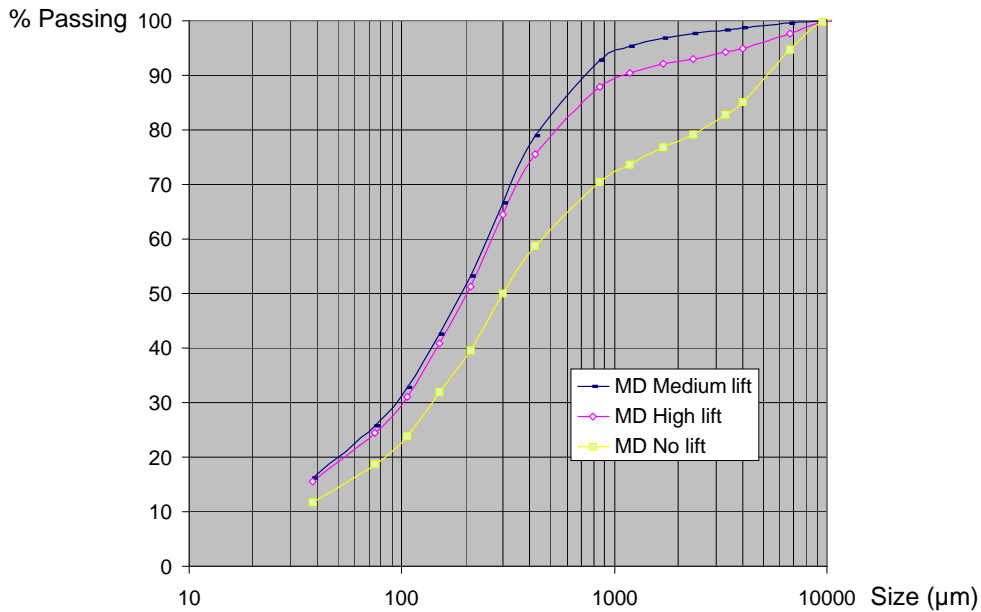


Figure 5: PSD – Mill discharge – Primary mill

In this specific case, it is obvious that a certain load expansion is needed to allow the coarse particles entering the media charge to be reduced.

Therefore, at this stage, direct measurement of the dynamics in the mill gives very valuable information to the operator. The evolution of media angle could probably help the operator to optimize the mill efficiency (plan liner change and / or adapt mill speed if possible). Studying the complete evolution of the media angle through the liner lifetime can lead to an improved liner design.

However liner design and grinding efficiency are using the media charge angle only. Other examples will also explore the interaction between the pulp and the media load.

INFLUENCE OF SLURRY PROPERTIES AND LOAD BEHAVIOUR IN TUMBLING MILLS

In 1988, Professor Moys, from University of the Witwatersrand in South Africa, published articles about the effect of slurry rheology and flowrate on mill behaviour. He highlighted the interaction between slurry and media in the mill by looking at mill grinding efficiency. At that time, it was difficult to acquire significant valuable information as robustness in an aggressive environment was not assured.

Twenty years later, the Sensomag® is able to show this interaction by looking on pulp position angle and media angle. The Sensomag® has been developed to continuously measure both ball load and pulp slurry positions inside a running mill. The main data are provided in terms of toe and shoulder angles.

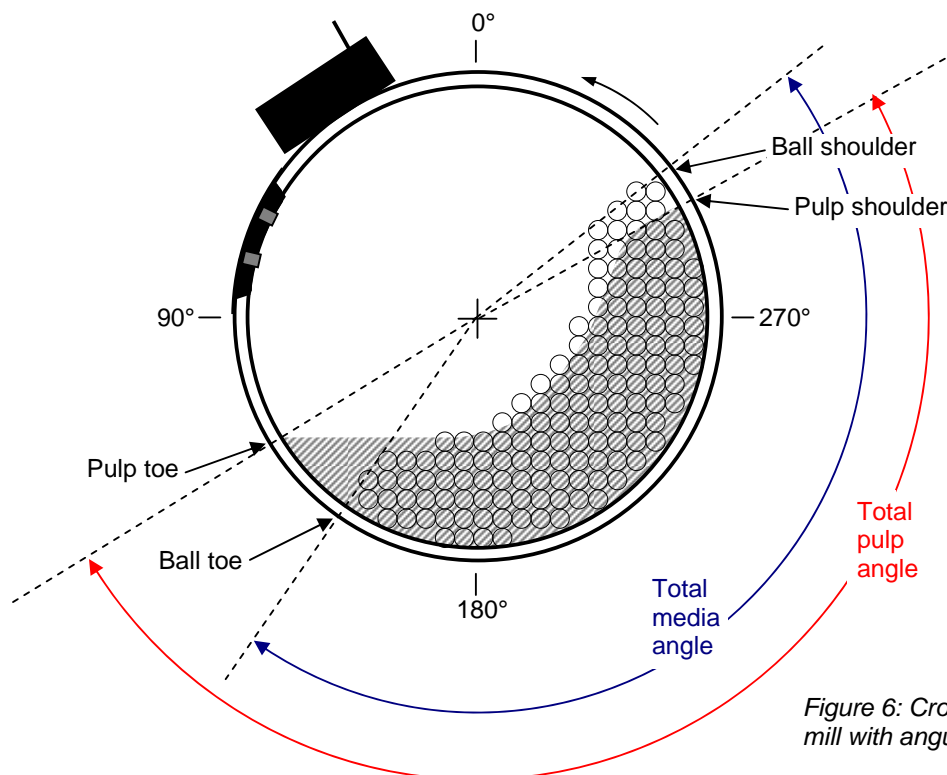


Figure 6: Cross section of the mill with angular references

The pulp density is an important parameter influencing grinding efficiency. In iron ore, for instance, a variation of 2 to 3% solid content in the slurry could lead to a difference of up to 10% on the energy cost (kWh/T) for a similar grind.

In the platinum industry, by increasing the solid content in the slurry, the product becomes finer. At a higher percentage solid than 73 to 74%, the grind becomes coarser again. At this content, a drop of grinding efficiency occurs.

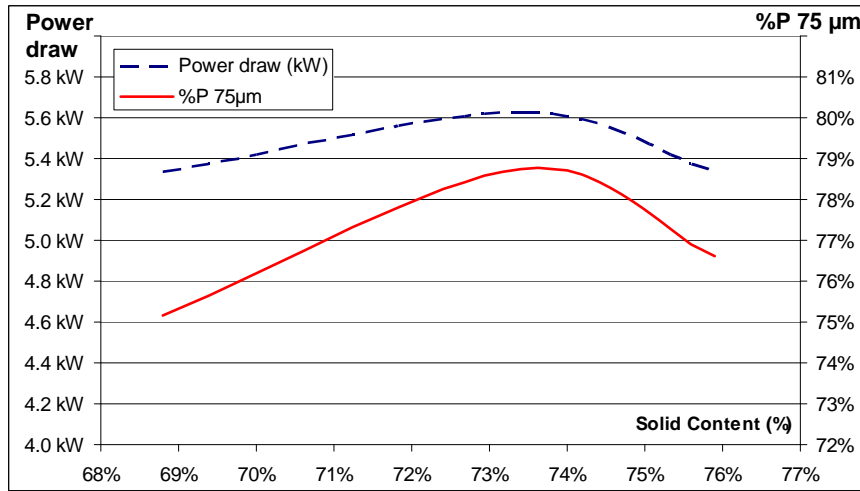


Figure 7: Mill efficiency evolution with pulp solid content

For a better understanding of the grinding efficiency drop, several tests were performed in a pilot scale mill (one meter diameter). The media and pulp angles were recorded by the Sensomag®. From 69 to 73% of pulp solid content, the media total angle keeps a constant value (184°) and the grinding zone fills up but, remains unsaturated (media angle > pulp angle). From 74% the media angle exponentially increases with pulp solid content. Unstable and inefficient milling conditions start to occur: the grinding media load is expanding.

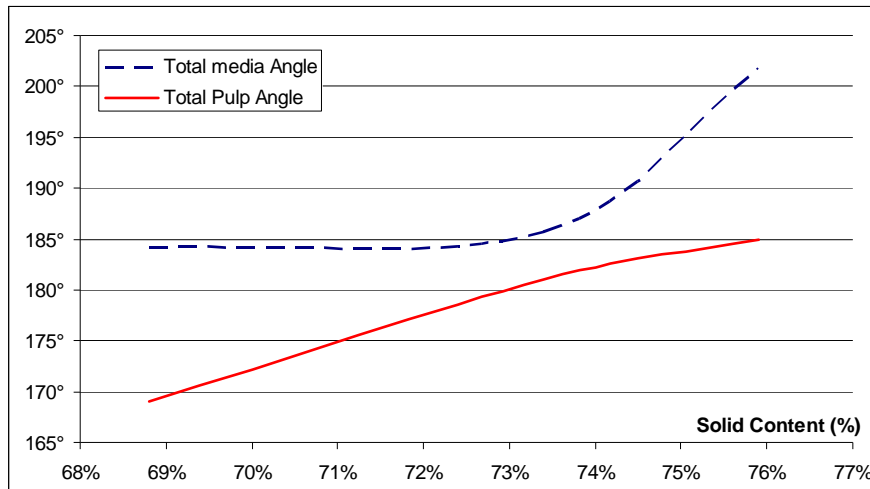


Figure 8: Grinding zone progressive filling with pulp solid content until load expansion

This test also shows that by feeding the mill with a too dilute pulp, the grinding zones between media are not saturated leading to high media wear rate.

So, variation in total ball angle can be detected and linked to grinding efficiency and charge expansion. This could help the operator to make the right decision and keep the mill running at the most favourable optimum pulp density (73% in the above example). One must keep in mind that the optimum is always very close to the unstable zone.

INFLUENCE OF BALL FILLING DEGREE

This paper illustrates the topic for a grate discharge mill. For a specific production rate in pilot plant, the increase of the ball level from 25% to 30% leads to an increase in product fineness. But, adding balls from 30% to 35% does not mean that the final product will go finer than 78% passing on 75 μ m as already achieved at 30% of ball filling degree. By plotting on a graph the energy needed to produce particle sizes less than 75 μ m in function of ball filling degree, the drawn curve shows the optimum filling degree for this specific case (figure 9).

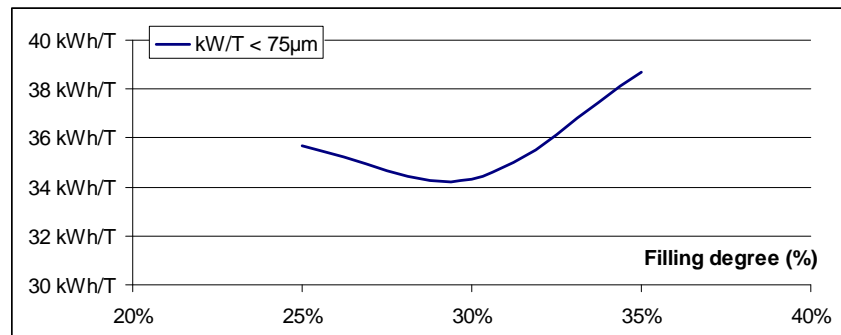


Figure 9: kWh/t < 75 μ m as a function of mill filling degree – Constant feedrate – Grate discharge

If the operator is working with a ball filling degree higher than the optimum, a waste of energy follows. As ball wear rate is proportional to the surface of the media charge, an extensive wear of balls occurs as well.

By measuring the angle position of both, pulp and ball charge, further information follows. For each ball filling degree, the grinding zones are not saturated with pulp. It means that a certain amount of balls is just rolling without pulp and therefore, those balls are just wearing each other without grinding.

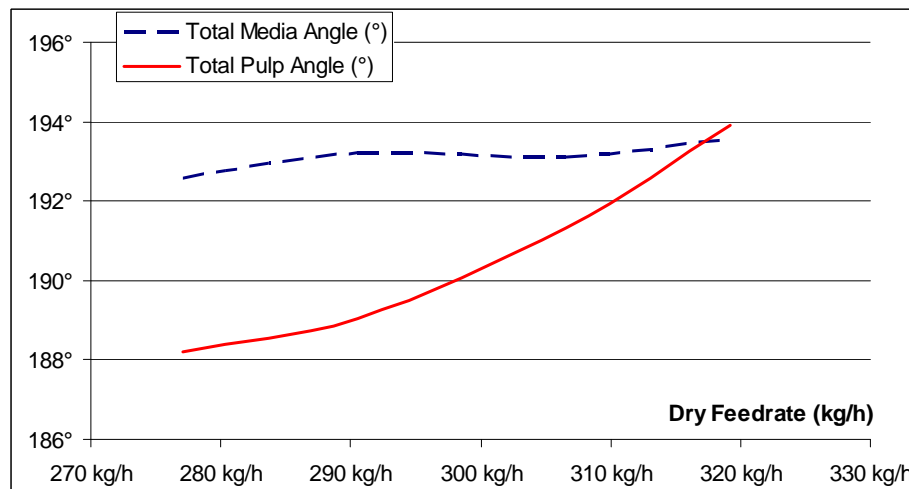


Figure 10: Grinding zone progressive filling with feedrate

At 35% of filling degree, by increasing the throughput step by step, the grind does not change. By following pulp angle and ball angle during the increase of throughput (figure 10), we could conclude:

- Those measurements could be an indicator of throughput restraint.
- For a given throughput, the right ball level for an economic operating condition, wear and energy could be determined and kept.

Figures 8 and 10 above show the interaction between ball and pulp angles. It is time now to show how to get those values and prove their reliability. The last part of this paper will describe the Sensomag in details and illustrate its operation using a few cases.

SENSOMAG® COMPLETE DESCRIPTION

The Sensomag® has been developed to continuously measure both ball load and pulp slurry positions inside a running mill. The main data are provided in terms of toe and shoulder angles. Please note the reference angles in the figure 6 above (angles counted in the same direction as the mill's rotation).



*Figure 11a and 11b:
Examples of polyurethane
sensor beams*

The principal element of the Sensomag® is a standard beam, made of special wear resistant polyurethane, installed inside the mill, and containing sensors, which perform direct measurements of ball and slurry presence. Grinding balls are detected by a magnetic based

proximity digital sensor. The slurry is detected by entering into contact with a two metallic electrodes conductive system.

There is no complex interpretation of any indirect signal of any kind such as noise, shell vibrations or mill power drawn.

The ball load and pulp slurry detection is performed, on a mill section, at every revolution. Those raw signals are sent through a wireless link to a central unit where they are processed.

The four angles are then computed and made available on line to the customer supervision system via a standard OPC link or 4 – 20 mA electrical signals.



Figure 12: Example of Sensomag® installation on the mill shell

As described in the first part of this paper, the knowledge of ball load and pulp slurry positions, inside a running mill, is a unique opportunity to optimise equipment usage, leading to quality and throughput increase as well as energy and media costs reduction.

The Sensomag® can also provide a ball load filling degree (in percentage volume) based on the various angles and mill absorbed power. This requires at least one mill shutdown to perform a manual ball filling degree measurement in order to calibrate the model.

Once calibrated, the Sensomag® can be used to finely monitor steel balls consumption, manage ball additions (top ups), reduce shutdown periods (required for grind-outs and crash stops) and increase safety by reducing the number of mill internal inspections.

In an industrial ball mill, the maintenance aspects consist of replacing the resin beam every three months. The batteries, supplying the complete system with energy, should also be changed on the same time basis (3 months) although they can last longer. These interventions can be scheduled to fit with monthly mill stoppages to avoid extra mill downtime.

EXAMPLE OF INDUSTRIAL RESULTS

The Sensomag® has been installed on several industrial grinding mills. Various validation tests have been conducted and with more still under investigation. Here are the main results of some of them.

Pulp level controller

The experiment was performed on a 4.8 m diameter grate discharge mill, equipped with a Sensomag®. The customer has built a special moving device (plug) that can partially block the outlet trunion in order to keep more slurry inside the mill. When fully in the trunion, this device is able to keep enough pulp inside the grinding chamber to change the mill discharge to an overflow one, with an 8 to 10% power drawn reduction. When fully out, it has no effect at all. The mill is back to its original grate discharge conditions.

The experiment consists in moving the plug fully in and measuring the effect on the pulp level thanks to the Sensomag®. Then, after stabilisation the plug was retrieved fully out, to go back to the original grate discharge conditions. All the angles measured by the Sensomag® are displayed in the graphs below.

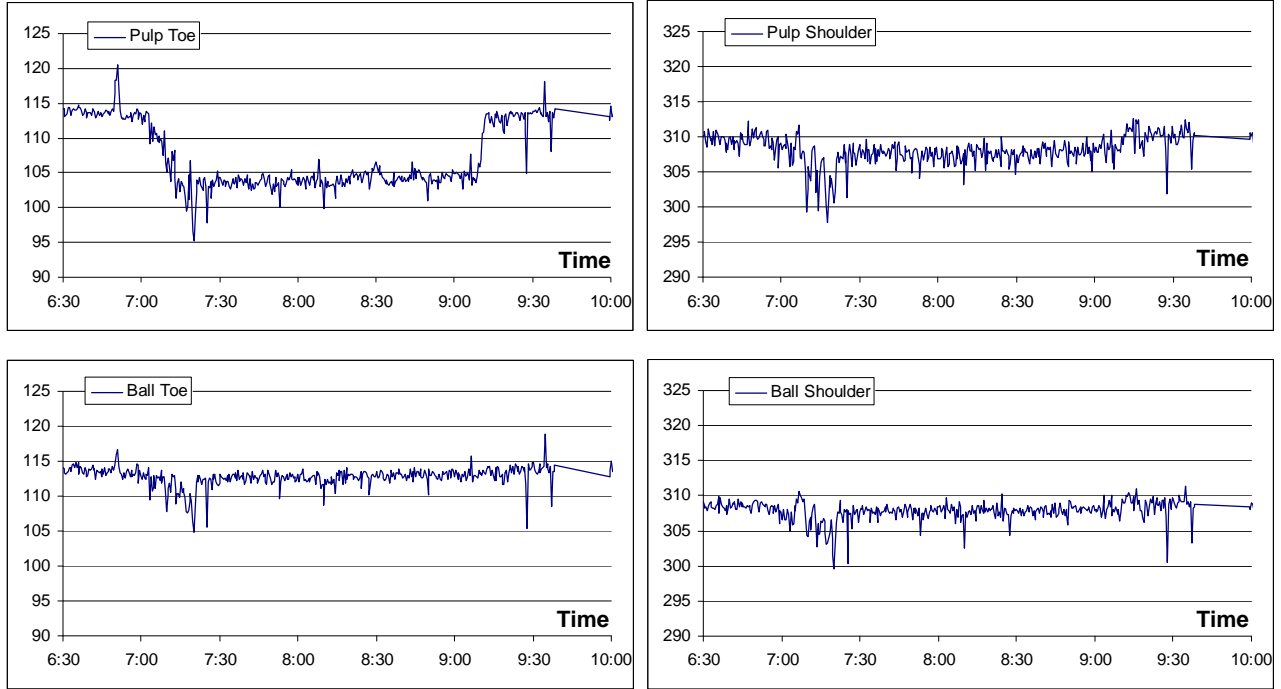


Figure 13a, 13b, 13c and 13d: Sensomag® angles during the plug in / plug out

As shown on the graphs, the pulp toe angle decreased by about 10° , while all other angles remained almost unchanged. A pool, typical of an overflow discharge mill, appeared. After the plug was driven out from the trunion, all angles recovered their original values.

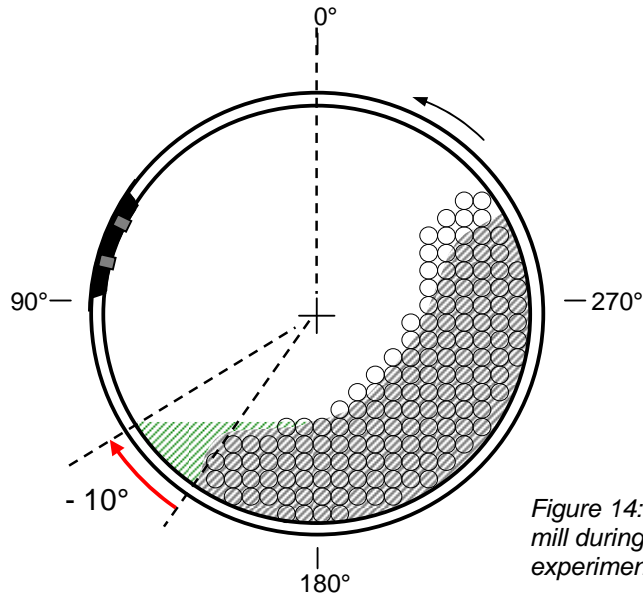


Figure 14: Cross section of the mill during the plug in / plug out experiment

This experiment demonstrates that the Sensomag® is able to follow, continuously, the evolutions of the pulp level inside a running ball mill. Other intermediate plug positions (different from fully in and fully out) could then be chosen in order to finely adjust the pulp level, leading to optimal grind for minimum power consumption.

What should also be pointed out in this specific case (in grate discharge conditions) is that both toe angles display very similar values (around 115°). This is also the case for both shoulder angles (310°). The conclusion could be that the grinding zone is properly saturated with pulp (optimal situation).

Ball wear without addition

The experiment was performed on a 7.3 m diameter overflow mill, equipped with a Sensomag®. The mill was left 42 hours running without any ball additions. All the angles measured by the Sensomag® are displayed in the graphs below.

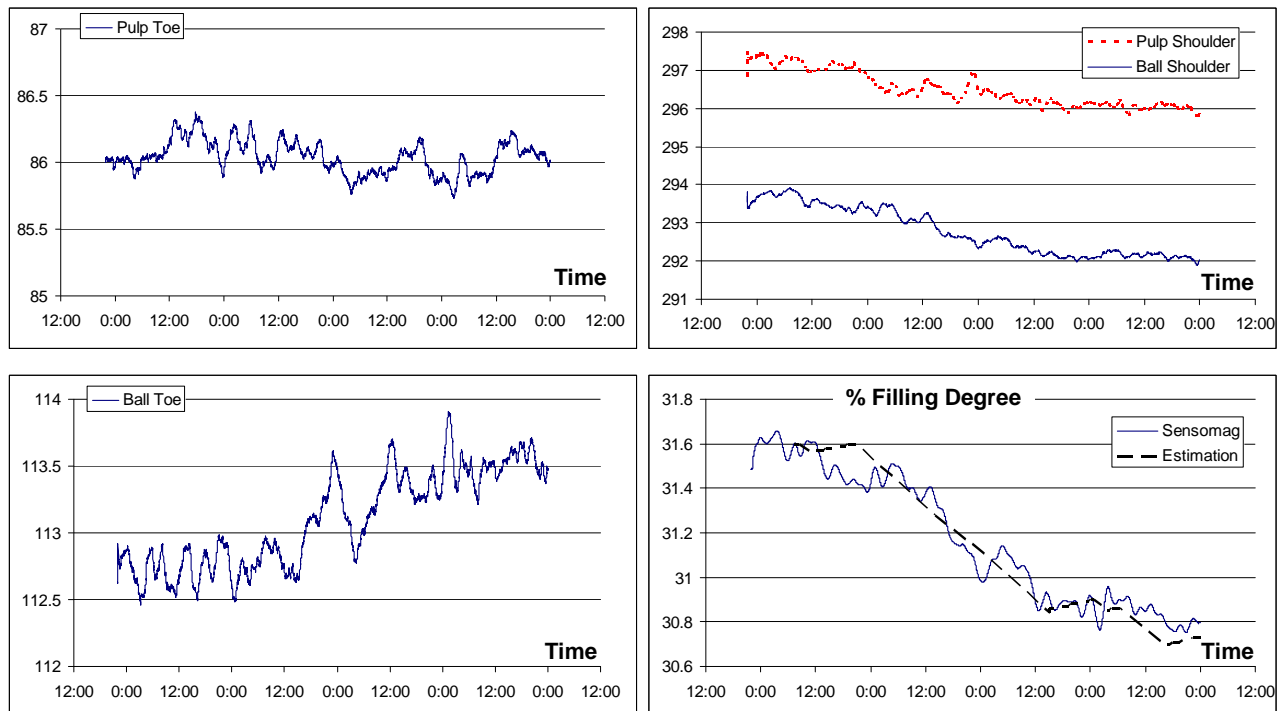


Figure 15a, 15b, 15c and 15d: Sensomag® angles during the ball wear experiment

As shown on the graphs, the pulp toe angle did not move. It remained constant at 86° (overflow discharge). Both ball and pulp shoulder angles decreased, in parallel, by about 1.5°. The ball toe angle increased by around 1°. The filling degree, computed by the Sensomag®, decreased from 31.6 % to 30.9 %. This signal fits correctly with a filling degree estimation, based on ball additions and a ball wear rate of around 40 g/kWh.

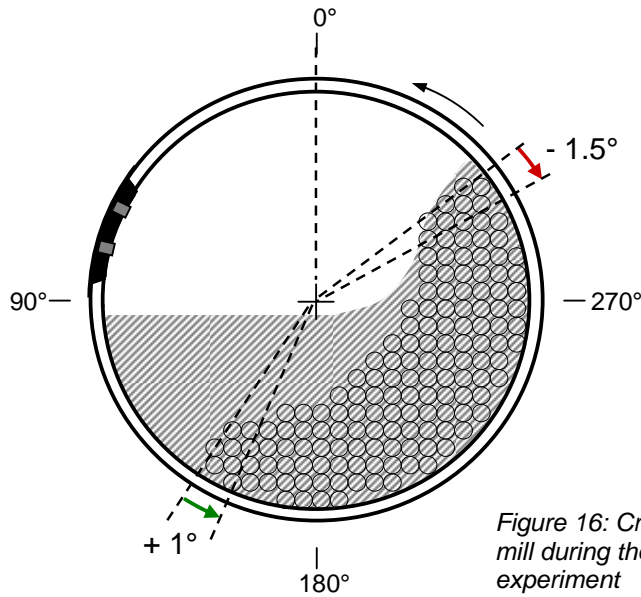
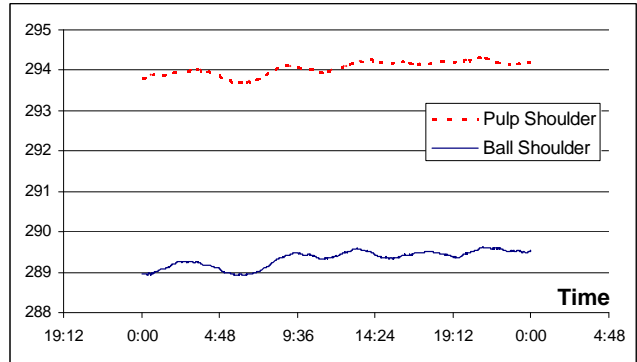
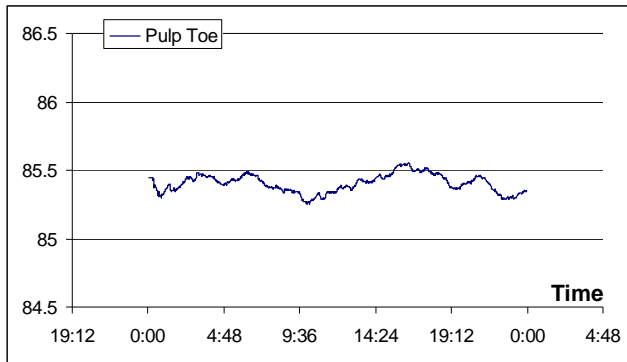


Figure 16: Cross section of the mill during the ball wear experiment

This demonstrates that the Sensomag® is able to continuously follow the evolutions (wear) of grinding media level inside a running ball mill.

Ball additions

The experiment was performed on a 7.3 m diameter overflow mill, equipped with a Sensomag® and a Magoload®. The Magoload® is an automatic grinding ball loading system developed by Magotteaux. At about 6:30 am, the filling degree setpoint on the Magoload® was increased by 0.2 % (from 30 % to 30.2 %). To reach this new setpoint, 4 Tons were added by batches of 225 kg every 2 to 3 minutes. The final target was reached at 7:30. All the angles measured by the Sensomag® are displayed in the graphs below.



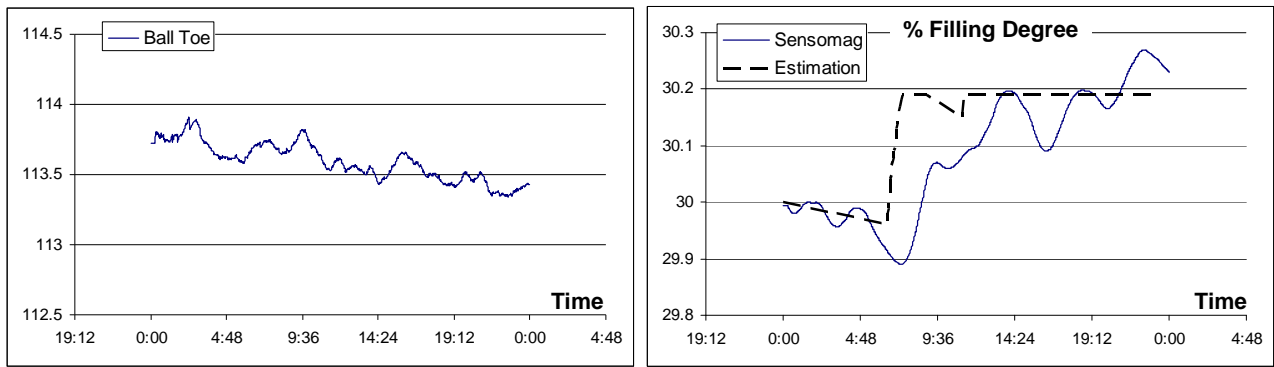


Figure 17a, 17b, 17c and 17d: Sensomag® angles during the ball addition experiment

As shown on the graphs, the pulp toe angle did not change very much as the mill is overflow discharge configuration. Both ball and pulp shoulder angles increased, in parallel, by about 0.5°. The ball toe angle decreased by around 0.5°. The filling degree, computed by the Sensomag®, increased from 30.0 % to 30.2 %. Again this signal fits correctly with a filling degree estimation, based on ball additions and a ball wear rate of around 40 g/kWh.

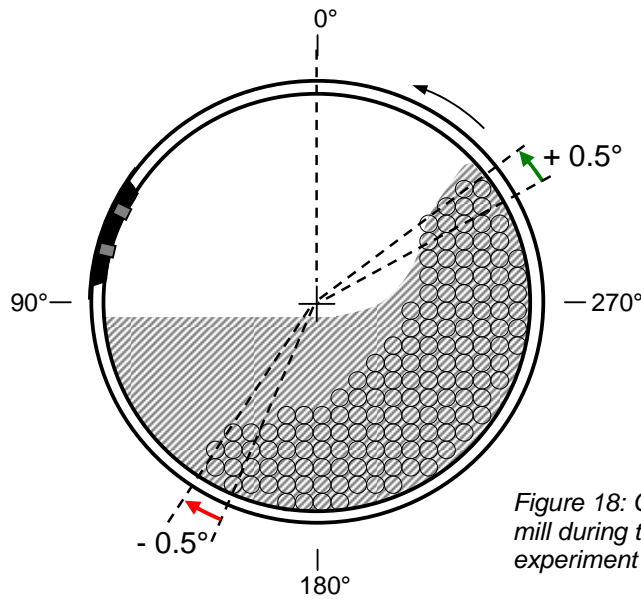


Figure 18: Cross section of the mill during the ball addition experiment

Again, this demonstrates that the Sensomag® is able to continuously finely follow the evolutions (additions) of grinding media level inside a running ball mill.

In the two cases detailed above, the pulp shoulder angle is a few degrees greater than the ball shoulder. This is an indication of a pulp density a bit too high: the pulp is sticking on the liner and lifted above the grinding media.

CONCLUSIONS

The Sensomag® is a unique tool that can provide continuous valuable information of what is really happening inside a grinding mill. It opens a wide variety of avenues to explore in order to optimise mill running conditions.

It is able to closely follow, independently, pulp slurry and ball load level evolutions inside the mill and provide key information, on line, to the plant engineers.

Sensomag® physically measures critical mill parameters that could be turned into valuable information for timely decision making and action.

Knowing the mill internal dynamics in terms of grinding balls and pulp slurry angular positions, given by the Sensomag®, could facilitate:

- Dry federate and water addition optimisation in order to run the mill with the grinding zone properly saturated;
- Liner design optimisation to obtain good relative movement of grinding media and pulp as well as avoid ball projection and liner breakage;
- Liner wear and efficiency changes monitoring in order to optimise liner replacement;
- Grate discharge design improvement to keep pulp level constant throughout the mill length;
- Load expansion detection (due to density change);
- Mill media filling degree control and optimisation, to reduce production costs while keeping the same grinding performance.

This list is not limitative and other promising optimisation avenues are still to be explored.

The mill filling degree is one of the last critical measurements that still requires, a mill shut down and is still performed manually at large intervals (every few months). The Sensomag® also represents the solution for this essential issue.

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