THE EYES HAVE IT: IMPROVING MILL AVAILABILITY THROUGH VISUAL TECHNOLOGY

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ABSTRACT

This paper describes the introduction of two unique tools that discard the longstanding notion that it is impossible to assess liner condition without stopping the mill and pulling the feed chute. Specifically, this paper details the tools used to provide real-time visual assessment and detailed liner wear monitoring of a running SAG/AG mill, using a MillWatch Camera Unit and the Kaltech iBolt, the intelligent mill liner bolt. The considerable and demonstrable value that these tools bring when used in concert is discussed in detail, as are the other possible uses for this technology in other applications such as HPGRs.

KEYWORDS

Camera, bolt, liner, reline, wear, mill, availability, SAG, MillWatch, Kaltech

INTRODUCTION

The inside of a SAG/AG mill (henceforth referred to as a SAG mill) has always been a place of mystery, primarily due to its inaccessibility resulting from the hostile, dangerous and enclosed environment inherent to the mill. Many millions of dollars have been spent attempting to empirically measure various indicators external to the mill (e.g., noise and vibration) in an effort to extrapolate this data into a description of the internal conditions. More recently, computer modelling and simulation has been increasingly explored in order to predict the dynamics of the mill internals. The idea of placing a camera in a running SAG mill has existed for some time, as an image of the internals of a running mill would, at least theoretically, significantly increase the value of the other empirical and simulated data. Furthermore, being able to assess the internal conditions of the mill liners and charge level and composition of a stationary mill without the time impost and safety risk of having to pull the feed chute and put mine personnel into a confined space has only enhanced the appeal of this idea. But implementation of such a camera system has only been spoken of in hypothetical and hopeful terms.

In a similar vein, the monitoring and measurement of liner wear has, since the first mills were used, also required an extended manual process of visual inspection and manual measurement of liner thicknesses and wear patterns. More recently, laser scanning inside some mills has been utilized as a method of capturing the liner wear profile. Being able to visually assess the wear of any particular liner without having to pull the feed chute and enter the mill is partially solved by an appropriate camera system. However, the more elusive idea of being able to measure liner wear of any particular liner in real time, without stopping the mill, is every bit as tantalizing to consider as gaining vision inside a running SAG mill.

Being able to combine both of these technologies to access real time and historical information about the conditions of the liners, grinding ball percentage, and overall charge level inside the SAG mill without the need to pull the feed chute, presents a huge opportunity for improving mill availability, comminution optimization and associated cost reductions, liner life prediction and reline planning, and comparisons of liner design changes or modifications supported by empirical data.

In the sections below, we discuss the implementation of a system that enables both of these ideas to become a reality. The system's two main components, the MillWatch Camera Unit (MCU) and the Intelligent Bolt (iBolt) are described separately, followed by further explanation of the system that combines them both. We also discuss the benefits already realized through existing unit installations, along with the potential benefits of future product development. Lastly, we outline other possible applications of MCUs and iBolts in other mining applications, including HPGRs and Ball mills.

SYSTEM CONCEPT AND DEVELOPMENT

MillWatch Camera Unit

In recent years camera technology has advanced at a rapid rate, enabling the capture of imagery that had previously been unattainable. The introduction of affordable, ruggedized high-definition (HD) video cameras that can be held, worn on your person, or mounted to a vehicle, has revolutionised conventional thinking and inspired the pursuit of new vantage points from which to capture all manner of recreational and instructional activities. Similarly, the widespread use of fixed "security" cameras in businesses, on city streets, and even on mine sites, to monitor people and processes has led to an acceptance of this technology as a legitimate means of providing a range of useful information, including the monitoring and optimisation of plant and equipment.

The idea and intention of applying this technology to SAG mills is not new. There have, no doubt, been many conversations which lamented the fact that the mysteries inside a SAG mill could not be directly observed via a camera, given the limiting assumption that such a camera could not survive the environment while providing a live video feed. Consequently, the pursuit of understanding the inner workings of SAG mills has turned to, and is limited by, the use of microphones, infra-red monitors, computer modeling, and other valid but externally based sensory or simulated technologies.

The concept for the MCU system was based on challenging this limiting assumption. By combining the "go anywhere" concept of ruggedized and portable HD video cameras with the process monitoring and optimising benefits of a fixed "security" camera, we designed a MCU which provides a live video feed from inside a running or stationary SAG mill. The first successful installation of a MCU, completed at the Canadian Malartic mine in Quebec, Canada, in 2014, marks the beginning of a new level of insight, information, and safety inside SAG mills. The system we have installed at Canadian Malartic enables mill managers, supervisors, metallurgists, and planners to see directly into the 38' SAG mill without having to pull the feed chute.

We undertook several development cycles to determine the level of protection and robustness required to operate effectively in the SAG mill for extended periods of time. The main features of the completed Canadian Malartic MCU include:

- HD pan/zoom/tilt infrared camera, with accompanying infrared lighting;
- An inbuilt microphone to provide audible feedback from inside the mill;
- Impact-resistant housing and protective doors to withstand the aggressive environment;
- Self-cleaning glass functionality to ensure clear vision at all times;
- PC Workstation and proprietary software configured to interface with the MCUs and control and record the video feed, including capabilities for remote access to the live video feed;
- Full access to stored video footage.

- Hardware interface with the iBolt2 (refer following section), electronically capturing the liner wear events as they occur, and logging, interpreting and transmitting that data.

Figures 1 and 2 show the system that we installed at Canadian Malartic, with Figure 3 showing a sample image taken inside the closed mill of the discharge end liners. This system is currently in operation and providing a host of benefits for the users. We review the benefits of using a MCU system in a SAG mill at length in a later section of this paper.

Figure 1 – MCU Camera and lighting housings mounted on the feed chute flange

Figure 2 – MCU Control boxes mounted on the side of the feed chute

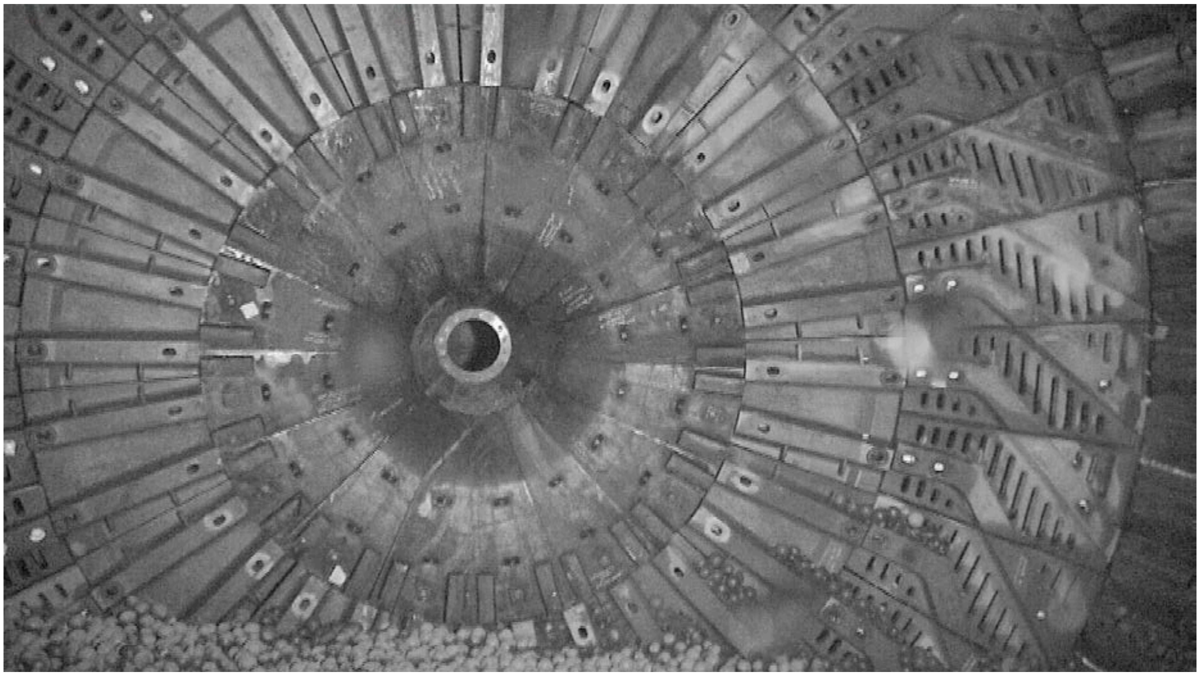

Figure 3 – Discharge end of the 38’ SAG mill at Canadian Malartic with feed chute in place

Intelligent Bolts

The prediction and monitoring of liner wear inside a SAG or Ball mill has traditionally been accomplished and confirmed by a number of different methods, many of which require people to enter the mill. These methods include laser scanning, template profiling, ultrasonic thickness measurement, physical measurements, and general visual inspection. Mill entry normally requires such actions as locking out of the conveyor and the water, electrical isolation of the mill, pulling the feed chute, blanking off the chute feed, atmosphere testing, checking for exploding mill balls and overhead hazards, making the mill safe for entry, posting a sentry, and reversing the cycle when done. These actions require a slew of permits and several people working over a number of hours on this cycle every time mill entry is required, and all the while the mill is nonoperational.

The least optimum method of monitoring liner wear involves waiting until the liner bolt heads wear completely away, resulting in leaking, loose and/or thrown bolts. Prior to the existence of intelligent bolts, this wear indicator event (of last resort) eventually occurred in every mill, and almost always resulted in damage to the mill structure itself to a greater or lesser degree.

Considering that the head of the steel liner bolt wears down as the liner wears, or the head can be extended or placed so that it does, a standard liner bolt can be reconfigured to be an “intelligent bolt”, being perfectly placed to act as a wear indicator receptacle. An intelligent bolt, or iBolt, is a regular liner bolt that is modified to accommodate electronic componentry along its length such that it will report a predetermined wear event or events from a running mill. Once converted, an intelligent bolt provides an additional or alternative method for the monitoring of liner wear and, most uniquely and importantly, it does so in real time and while the mill is still running. Several versions of the iBolt have been created with differing levels of data resolution and reporting, with further development ongoing. The main features of the original iBolt are as follows:

- The iBolt features a light indicator that is configured such that when a set liner wear point is reached in the bolt head inside the mill, a fixed or flashing LED light embedded in the thread end of the bolt, outside of the running mill, is activated for up to 60 hours before the battery is depleted. For example, a series of iBolts in the high wear areas of the mill shell could be arranged to trigger at liner wear points of 50, 65 and 80%, or as otherwise determined by the mill operating and planning requirements.
- The iBolt is designed to help monitor and predict liner wear in real time, while the mill is still running. Once triggered, the iBolt is dependent on someone observing the LED lights during the 60-hour iBolt battery life window. In a typical SAG mill, best practise is to utilise an array of iBolts spread out over the known high-wear areas on the shell and feed head, so as to ensure capture of the broad and singular wear events. Sufficient iBolts should be placed so that, wherever possible, a number of readily observable lights are triggered simultaneously or in quick succession.
- This iBolt can also be used for testing and confirming the usefulness of position placement of intelligent bolts, or for general concept testing in other liner wear applications, such as feed chute bolts. The original iBolt is a standalone unit in as much as it does not require any hardware or software support.

Additional features and functionality of the iBolt's successor, iBolt2, are as follows:

- The iBolt2, with multiple decrements of wear measurement, is a fully electronic version of the original iBolt and consequently requires hardware and software support. The iBolt2 electronically reports 4 or more wear points from the one smart bolt in real time, while the mill is running. It uses the MCU hardware and software system to send reports of any wear events directly to the desired recipients as email messages.
- The iBolt2 uses the same PC Workstation and proprietary software used for the MCUs, which provides capabilities for remote access to the live wear data on any iBolt2;
- Full access to stored iBolt2 wear data for analysis in maintenance planning;
- We are continuing to develop the iBolt2 to include even more features and functionality.

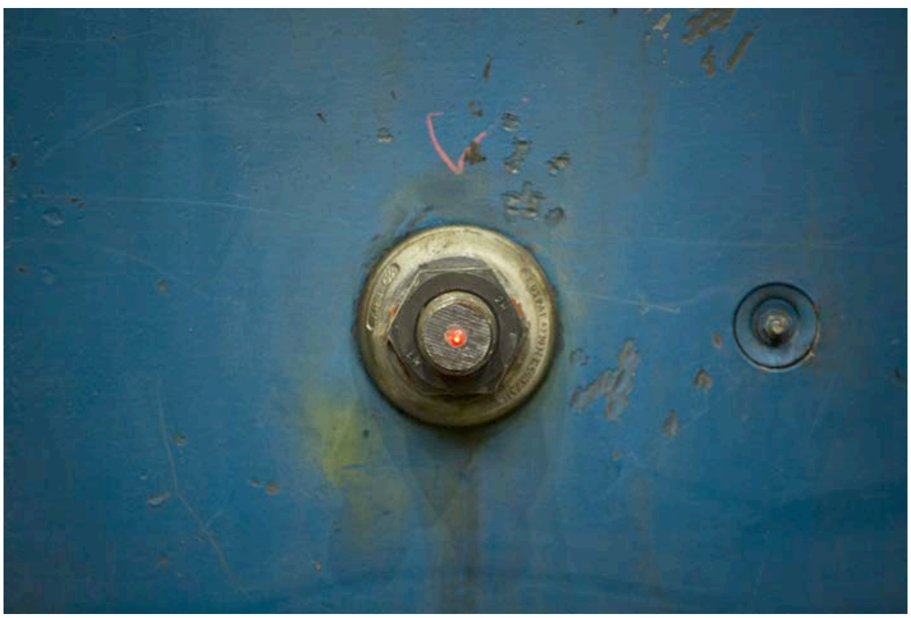

Figure 4 – An activated iBolt installed on the shell of a SAG mill

Figure 5 – The iBolt showing the elongated head and indicator light

INTEGRATION OF COMPONENTS INTO THE FULL SYSTEM

The two system components, the MCU and the iBolts, are able to be used independently of each other in any given mill, as is currently the case at Canadian Malartic. While both components share the same software platform and a significant portion of data transmission/receiving hardware, it is possible to install only one of the components in a mill at a time, as each component is capable of delivering significant operational value in its own right. If only one component is initially installed in a mill, the second component can be added at a later date. However the two components are best used in cooperation for maximum effect on improving operational efficiencies and reducing risk.

When both components are integrated into the full system, the complete functionality of the system can be realised. In addition to the features available from each individual component, the full system provides the following features:

- Live information from both camera feed and liner bolt wear simultaneously, available without having to stop or enter the mill;
- An integrated software package that brings together both the camera vision and liner bolt wear information for the user, including the option of making the data available to any authorised user on their own desktop or mobile device;
- Archived storage of video footage and bolt wear data for review and analysis at any time;
- The ability to connect the system software with the SAG mill control data outputs (specifically mill rotation speed) so that any unplanned mill stoppages automatically trigger a recording of video footage inside the mill for later assessment;
- Automatic alerts that are logged and sent via email to specified users when specific events occur (e.g. liner bolt wear point reached, or a mill stoppage);

SYSTEM BENEFITS – PRESENT AND FUTURE

As we mentioned earlier in this paper, the MCU and iBolts present unprecedented opportunities for increasing mill availability, decreasing costs, and improving maintenance planning. It is important to understand these benefits, as each of the benefits we outline below has the potential to unlock significant value and safety improvements for the concentrator plant. Those benefits that have already been realised, as opposed to those that are theoretically possible but have not been verified empirically, are noted accordingly.

Increased Mill Availability

Mill availability remains one of the most significant markers of efficient mill operation. The significance of keeping the mill running for the maximum amount of time in any given period is fundamental in meeting the key performance indicators for any mill manager. Mill stoppages, both planned and unplanned stoppages, can significantly lower mill availability and output tonnage. Strategies and tools that reduce mill stoppages, both in frequency and duration, are therefore extremely important.

One of the key benefits to utilising both the MCU and iBolts is the ability to significantly reduce the mill down time required to perform mill or ball charge inspections. Typically, several hours of mill availability are lost for each mill inspection event. Plant isolation procedures, moving the feed chute, clearing the mill so that it is safe for entry, the inspection process itself, and the reversal of these steps, can easily consume several hours. If the feedchute is difficult to move, or a delay in the removal of the isolation tags of a forgetful individual occurs, this time can expand considerably. By contrast, use of the MCU and iBolts can eliminate the requirement for people to enter the SAG mill during a mill inspection, resulting in a large number of additional hours of mill availability being gained each year, in addition to freeing up considerable man hours. We have found that through the use of an exhaust fan on the discharge trommel, it has been possible to see clearly into the mill and begin conducting an inspection using the MCU in less than 5 minutes after the mill has stopped.

Figure 6 – Exhaust fan connected to the discharge trommel

To illustrate the impact of this, Table 1 shows an example of the increased mill availability made possible through the use of the MCU. This example assumes that the feed chute is easily removed, the mill is not fully hosed out prior to people entering the mill, and that there are no delays in the de-isolation process.

Table 1 – Comparison of time taken to conduct typical mill inspection with and without a MCU

Task	Without MCU Elapsed time (hrs)	With MCU Elapsed time (hrs)
Mill Stop	0.1	0.1
Plant Isolation	0.5	-
Remove Feed Chute	0.15	-
Mill Safety Check	0.5	-
Conduct Inspection	0.2	0.2
Reinsert Feed Chute	0.15	-
Plant De-isolation	0.5	-
Mill Start	0.1	0.1
Totals	2.2	0.4

Throughout the course of a year, assuming monthly planned inspections and several unplanned inspections, the additional mill availability produced by the MCU can easily exceed 30 hours per year on inspections alone. When the mill is new or is experiencing operational difficulties that require more frequent inspections, or when attempting to set the correct charge level for a mill reline, further improvements in mill availability are achievable by using the MCU to inspect the mill. We describe this in more detail in the following sections.

Comminution Optimization

Understanding the internal mechanics of a running SAG mill has been an ongoing pursuit for researchers, metallurgists, and mine managers for decades. An understanding of the internal mechanics of mills is listed by Powell & Morrison (2007) as a key requirement to producing validated comminution models. While we do not claim that the MCU reveals all of the required information for model validation, we do believe that the MCU can significantly expand current understanding into the internal mechanics of a mill. Specifically, the position of the toe of the charge as it relates to the mill speed, liner profile, and ore characteristics and volume, is a key component in characterising the internal mill mechanics. For illustration purposes, we have been able to produce images (refer Figure 7) using the MCU which clearly show the position of the toe of the charge while the mill is running, in this case at 7.5 rpm. The prominence of sparks in the image clearly shows the portion of the charge that is making contact with the shell liners, thereby highlighting the exact position of the charge toe under these circumstances.

While further refinements of the software and camera settings are still required to provide greater detail and accuracy of the position of the toe of the charge when the mill is under full load, we believe these early results clearly show that obtaining live imagery of the inner mechanics of a running SAG mill is achievable. For research purposes, we believe this type of imagery could provide excellent information suitable for validation of discrete element modelling and other mathematical tools aimed at simulating comminution. In practical terms, we believe a visual image showing the toe of the charge in a running mill will be invaluable in informing mill operators about the performance of their mill and behaviour of the charge in real time.

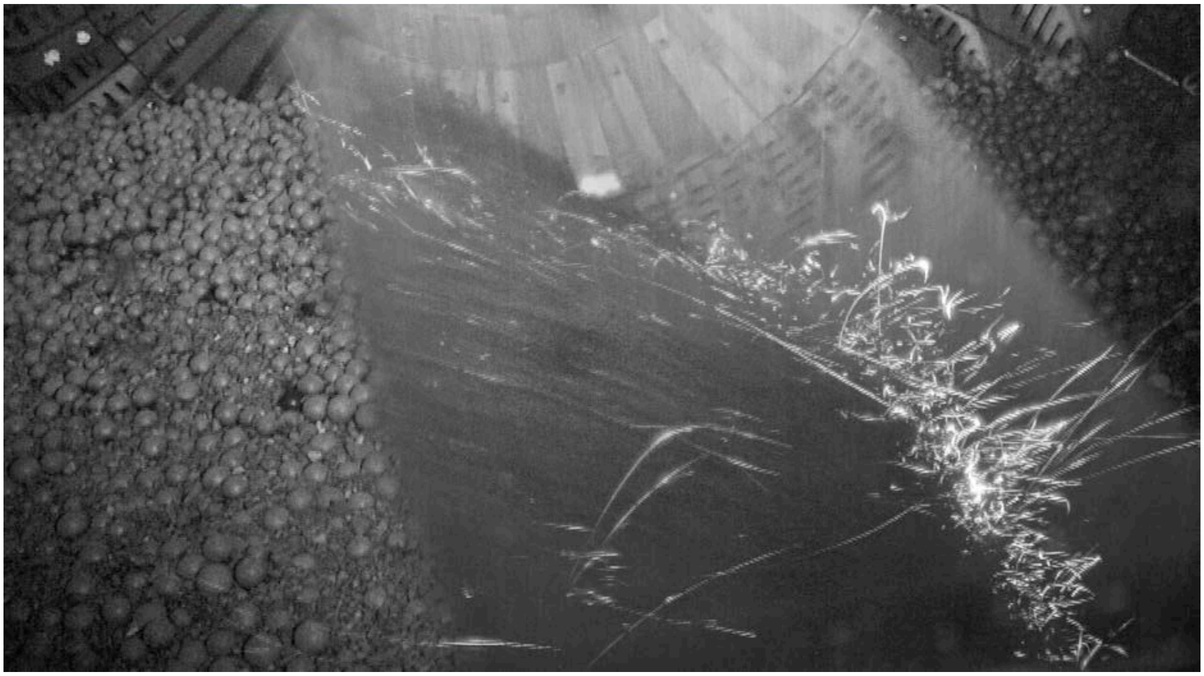

Figure 7 – Composite image showing the toe of the charge in the 38' SAG mill at Canadian Malartic at approximately 7.5 rpm overlaid with the stationary charge position

Maintaining an optimum charge height and composition in a SAG mill remains one of the fundamentals for efficient mill processing. Operating with low charge levels can result in serious damage to liners, and cause breakage in balls and bolts due to direct impacts by balls on the shell above the charge toe (Royston, 2007). Conversely, high charge levels require higher mill speeds and increased energy consumption, lowering mill efficiency. While mill weight may give some indication of the charge level, assumptions about liner wear and the ball to ore ratio can provide misleading answers, hence visual inspection remains the most reliable method of establishing the current charge level and composition. Even in older mills that have established patterns of behaviour and are well known to their operators, it is possible for the charge level and composition to drift away from their optimum over time without regular inspection of the charge. The MCU enables operators to check the charge level and composition (refer Figure 8) within minutes of a mill stop, and without the need to pull the feed chute. Hence, it should be possible to perform these checks on a regular basis with no more than 15 minutes of downtime for each check, enabling the operators to quickly reset the charge level and composition back to their optimum levels when required.

Reduction of Safety Risks

The entering of a mill, as with the entry of any confined space, inherently comes with an increased degree of safety risk. Overhead hazards in the form of cracked liners, lodged mill balls, suspended rocks and mud, a very hot and steamy environment, chemicals in the mill, fogged safety glasses reducing vision, exploding mill balls or deep mud, ladders, unique slip/trip/fall hazards, and a very challenging rescue environment. All of these confined space risks are best controlled by eliminating them altogether, wherever possible. The MCU and iBolts make it possible to significantly reduce the number of mill entries required.

Figure 8 – Charge composition check

Setting the Charge Before a Reline

The setting of the optimum height and consistency of the charge for the relining of a large grinding mill is critical, both from a safety and reline efficiency perspective. The liners that are to be changed out during a specific reline determine the required optimum height of the charge.

Most maintenance operations have a person on their team that has developed a “system” over time to set the charge height at what they hope will result in more or less the correct level for a particular reline scope of work. For example they may, in a large SAG mill, shutdown the ore feed and grind out the charge for a set amount of minutes to exhaust the mud and water, hopefully without over grinding so as to energize the steel balls and cause them to explode. They may then add some selected small particle dry ore feed for several minutes while rotating the mill, then make the decision to stop the mill and go about the process of locking out the conveyor and pulling the feed chute to look at what they have as a charge level. Others may use the weight of the ore in the mill as an indication of ore charge level, hoping that the scales are correctly calibrated. In many places it has been more of an art than a science.

Regardless of how it is done, without a confirming view into the mill, sooner or later the charge level is set at the wrong height and/or ore condition, the conveyor is locked out, the feed chute is pulled and the mill is handed to the relining crew. Many times the reline can be performed with a charge level that is not in the optimum height range, but safety and efficiency are always compromised, sometimes significantly so. A reline can take 10 or 20 hours longer than it should with the wrong charge level or charge consistency, and at a significantly higher risk. Sometimes it is simply impossible to reline from a charge level and condition that is too far from optimum, and ore has to be added or removed from the mill. Correcting an unworkably wrong charge level or consistency takes time, usually adding 2 to 4 hours or more to a reline. That usually means that many other maintenance people or contractors are also on hold, waiting for this issue to be resolved before they can start.

Having a camera in the mill helps expedite the process of providing the ideal ore charge level for a particular reline work scope, each and every time. It makes it a fast and easy process for anyone to follow. Additionally, others could be logged into the camera system remotely and follow and confirm this setting of the charge level.

Improved Liner Life Prediction and Reline Planning

Liner wear prediction is typically based on the tonnage processed, calculated against historical wear data per ton processed, and is confirmed by regular or semi-regular physical monitoring of the liners themselves. While this approach is proven and generally workable, it has some weak points in that:

- It is only as accurate as the equipment and technique used to perform the measurement;
- It is subject to the varying hardness of the ore; and
- It is monitored by the inclination of the operators to avoid shutting down the mill to perform a measurement because taking the mill offline for some hours each time is "counterproductive."

Even the most conservative of operations people have been occasionally caught out by premature liner wear due to some arbitrary issue, such as a loss of accuracy or calibration on the scale on the conveyor feeding the mill.

This premature liner wear itself is not necessarily calamitous, but as a minimum the result can be that the mill is opened for a regular inspection with the expectation that there is 4 - 6 weeks' worth of wear remaining on the liners, only to find that the liners are worn out and need changing immediately. Often, as with any unplanned shutdown, the professional contractors that are normally scheduled to support the shutdown are not available or have reduced availability, and the lack of experience of the stand-in team results in the plant being offline for an extended period, reducing mill availability and incurring maintenance cost overruns.

Occasionally the premature liner wear occurs in between liner bolts so that even the "last resort" leaking liner bolt wear indicator is not present. Typically when such a location specific wear event occurs, damage to the mill structure follows, and this damage to capital equipment can be quite significant and almost always irreversible. The MCU, coupled with correctly positioned and rigged iBolts, should eliminate the possibility of being caught out by the premature liner wear event.

Conversely the MCU and iBolt can also facilitate the extending of the time between shutdowns by providing affirmation of predicted liner wear, both visually and electronically, as the liners wear. In such a situation, these tools bolster the existing monitoring process and bring an increased layer of certainty to shutdown planning.

Comparing Performance of Different Liner Designs

The ability to customise and modify liner designs presents significant appeal in the pursuit to increase mill efficiencies, maximise mill throughput, extend liner life, and decrease the time taken to remove and replace worn liners during a reline. However, the trialling of a new liner designs is not without risk, and empirically determining whether, in particular, a new liner design is wearing better than a previous iteration can require significant manual measurement or laser scanning of liner thickness during the liner lifecycle.

Through the use of iBolts and the MillWatch software, it is possible to record and store liner wear information without the need for manual measurement of liner thickness, or indeed the need to stop and enter the mill to perform these measurements. By collating historical and empirical data showing liner wear rates for specific liners at particular spots in the mill, it should be possible to directly compare the wear performance of different liner designs using empirical data.

Understanding Liner Wear Patterns

In addition to performing comparisons between different liner designs, the liner wear patterns in the mill are essential in understanding the mill characteristics. Banisi and Hadizadeh (2006) list the liner condition as the most important factor in mill availability. They demonstrated empirically that the liners within a SAG mill do not wear evenly throughout the mill or even along the length of a liner, and concluded that the variations in liner wear could dramatically affect decisions about liner design and replacement. Using iBolts and MillWatch software, we anticipate it will be possible to automatically map wear patterns within the mill and compare this data against the mill parameters (speed, throughput etc.) and ore characteristics over specific or indefinite time periods without stopping the mill.

Figure 9 – View by the MCU of the shell liners in the 38' SAG mill at Canadian Malartic

Troubleshooting Your New SAG Mill

When commissioning a new concentrator and commencing production, the process of bringing the mill through the testing period and ramping it up to and beyond its design capacity inevitably presents some unique challenges. Inside the mill, many of the optimisation challenges encountered are expressed in the condition of the liners. Cracked or fragmented shell liners, discharge grates with cracked ribbing, peening or significant metal flow, ball chips and pegging, and an increased incidence of broken bolts are the "normal" conditions one would find in a new mill.

There are a number of circumstances that could contribute to this general liner condition, foremost of which would be a "low ore event", where ore was not added for a short or extended period yet mill speed was maintained. This results in direct striking contact between the mill balls themselves, as well as similarly undesirable contact between the mill balls and the liners. There may be other contributory factors to the liner damage, such as the accidental introduction of tramp metal to the mill, or a portion of a liner coming loose in the mill.

Whatever the cause, utilising a MCU during this mill ramp up stage would enable mill operators to reduce the risk of liner damage and potentially fast track the process of bringing the mill online. As the primary function of the MCU is to enable fast and safe mill inspections, the MCU contains the capability to identify or prevent several of these issues directly. Specifically, this would include:

- Regular checking of the grinding ball level. This process is performed more often with a new mill, and the execution and refining of new mill isolation and entry procedures with new teams of people generally takes longer. Performing this check regularly without pulling the feed chute would reduce safety risk exposure and save significant time;
- Monitoring of a cracked liner. Should a liner crack but not fragment, the liner could be regularly monitored for ongoing condition assessment using the MCU without pulling the feed chute;
- Setting the mill for change out of a broken liner. For example, if a discharge grate was broken and was discharging mill balls, the grate could be located, the mill positioned for changing and the charge set for the change-out prior to pulling the feed chute;
- Locating and removing tramp metal. Should it be suspected that tramp metal had been introduced to the mill, the MCU could be used to confirm the presence or otherwise of the tramp metal with the feed chute remaining in place. If the presence of tramp metal was confirmed, the MCU could be used to provide feedback for the mill inching such that the tramp metal was positioned on top of the charge and ready for removal, prior to the pulling of the feed chute;
- Opportunistic monitoring of condition of the liners. By linking the mill speed to the MCU software, the MCU can be programmed to automatically perform and record a visual sweep of the inside of the mill whenever the mill speed remains at zero for longer than a pre-set period of time. By doing so, this would provide additional information for those tasked with monitoring the liners, even when there wasn't a plan or sufficient time to look inside the mill during the stoppage;
- Setting the charge level for relining. In a new mill, it is usually more challenging and time consuming to set the charge level for mill relining, as there is limited or no historical data on which to base protocol. By using a MCU, this task becomes quick and simple;
- The ability to perform inspections inside the mill while the mill is running presents a host of other opportunities. The full ramifications and benefits of being able to visually assess and understand what is happening or, perhaps more importantly, what is not happening inside the new mill at various speeds and charge levels is yet to be fully explored;

- The MCU contains a built in microphone, uniquely placed inside the mill. Increased decibels or irregular noise patterns recorded by the microphone inside the mill could indicate a low ore event or tramp metal, or would at least warrant closer inspection by operators.

FUTURE PRODUCT DEVELOPMENT AND APPLICATIONS

In this paper, we have described the application of the MCU and iBolt technology to SAG mills. Development of these products is continuing, particularly in relation to the commercialisation of an iBolt which is fully integrated into the MillWatch software. Additionally, we are continuing to develop the existing technology to provide the following capabilities within the context of SAG mills:

- Improving software and image management to more easily produce clearer views of the toe of the charge while the mill is running at full speed and load;
- Adaptation of the MCU design so that it is easily adapted to SAG mill feed chutes that do not have a large front flange;
- Improving the accuracy of the liner bolt wear measurement to provide continuous measurement of the bolt wear, rather than discreet measurement. This would provide a live output of an exact ‘percentage wear’ of any iBolt.

Other possible opportunities to expand the use of the MCU and iBolt technologies beyond SAG mill applications are listed below.

MCUs in HPGRs

A number of similarities exist between the SAG mills and HPGRs with respect to the need to conduct physical inspections inside the plant. The process of inspecting the rolls in a HPGR also consumes significant downtime, reducing HPGR availability. Additionally, some sites have changed out the rolls in their HPGR prematurely, primarily because the degree of difficulty associated with regular inspections of the rolls condition leading up to change out is too high and the downtime too costly. The MCU technology is easily adapted to HPGRs, and can be applied in any situation where improving HPGR availability is a priority.

iBolts in Ball Mills

While the value proposition is not always as compelling for the use of this technology in ball mills as it is in SAG mills, there is nonetheless significant value to be gained in applying this technology to some ball mills. In particular, grinding circuits that have only one large ball mill for each SAG mill could especially benefit from this technology, as they share the critical path with the SAG mill and more often have larger steel liners, rather than rubber liners. Additionally, the liners in the high wear areas of many ball mills often fail early and suddenly, prompting an emergency shutdown. This type of unplanned event would be eliminated with the use of the iBolt.

Other Mill Types

The MCU and iBolt technology is also potentially applicable to verti-mills, rod mills, cement mills, or any other critical-path equipment for which internal condition monitoring is able to reduce downtime or improve safety by removing risks to personnel. We are continuing to search for suitable applications for this technology that meet these criteria.

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