MECHANIZED BOLTING – ON-BOARD DRILLING AUTOMATION AND A CHANGE IN THE SUPPORT REGIME IN LOW-PROFILE MECHANIZED MINING

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Abstract

The safe and optimal installation of roof support remains one of the biggest challenges in underground mining today. Traditional hand-held, roofbolt installation in conventional mining has been replaced, in a lot of mining operations, by mechanized equipment. This was a first step to moving the operators out of the unsafe working environment and a start on the trend toward a changed support regime in mechanized mining. However, the challenge of handling of the drill steel itself, as well as inserting resin cartridges and bolts, remains a major hazard and the cause of many lost-time injuries.

The paper describes and discusses developments in this area, of mechanized bolting and on-board automation, presenting solutions to known problems, achievements to date, and future developments.

The solutions presented will identify with addressing customer needs while touching on possibilities for further technology changes, keeping focus on the safety aspect for operators and the need to bring the operators even further away from the unsafe working environment. The-state-of-the-art technology in mechanized bolting equipment is presented and a brief outlook on the past, current, and future developments is given.

Brief history of the mechanization of roof support

Mining has always been regarded as a dangerous profession, and there are few places more hazardous than below an unsupported section of ground. Falls of ground often results in severe injuries or death and brings undue pain and suffering to the workforce and their families.

Although safety has always been a consideration in the process of extracting precious resources from the Earth, it has never been as prominent as it is today. Mining houses, original equipment manufacturers, and regulatory and legislative authorities all put safety in the forefront when it comes to mining. Figure 1 depicts the trend of reducing fatal accidents while at the same time increasing production in the platinum sector during the period 2001–2010.

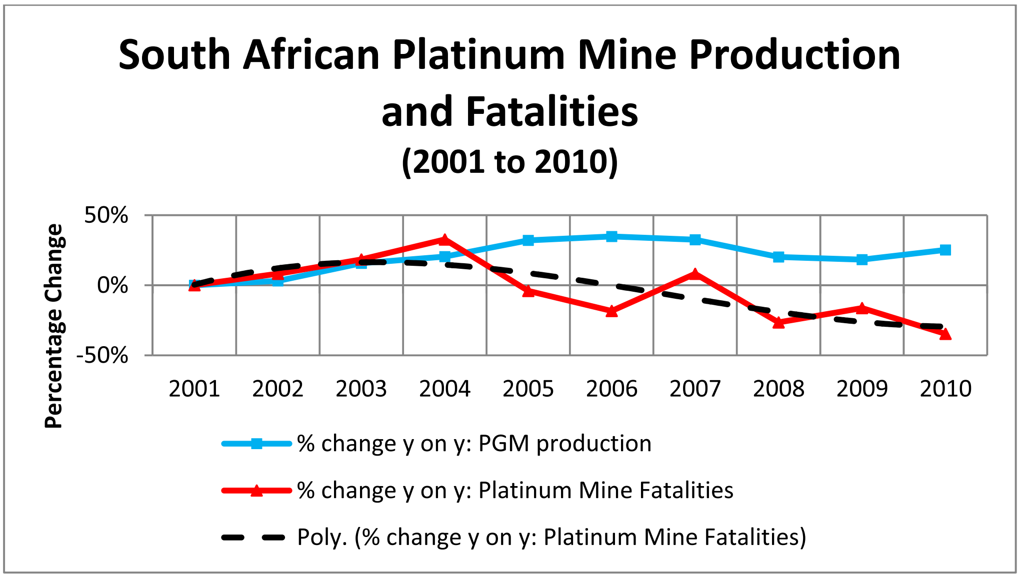

Figure 1-Mine production and fatalities in the South African platinum industry[1]

It was during this time that mechanized mining truly took a foothold in the industry, and while this successful trend in safety improvement cannot be solely attributed to mine mechanization, it is reasonable to deduce that the increased presence of machinery in the mining environment influenced safety in two different manners:

1) **Direct**: mechanized mining removed the miners from dangerous areas and offered them protection from falling ground and other environmental hazards, as well as improved working conditions through ergonomic principles in design
2) **Indirect:** recognizing the new dangers of the mechanized power interacting with miners underground brought about 'safe-work procedures', renewed focus on safety, and a placed greater emphasis on liability, risk, and how to reduce and, where possible, mitigate such exposure.

Recognition of the need to remove the mine worker from a hazardous environment led to the development of the mechanized roof bolter. In its original form this solution offered the workforce the ability to distance themselves from the unsupported areas, but only for limited periods of time as drill steel, drill bits, and resin cartridges still needed to be exchanged during every step in the process.

A natural step forward was to reduce the operator's time under unsupported rock even further by fully mechanizing the roof bolter. What is significant about all this is that while all these industry advancements were taking place, Sandvik, together with the South African platinum mining industry, was accomplishing them on a low profile mine height basis, once again ensuring that safety, productivity, and reliability were of precedence.

Rock reinforcement in mechanized low-profile mining - industry best practice

The Best Practice Industry Workshop[2] on Rock Engineering in Hard-rock Room and Pillar Mining, arranged by the Centre for Mechanised Mining Systems of the University of the Witwatersrand, was held from 16 to 18 February 2011. It was a follow-on event from a previous Best Practice Workshop that covered all aspects of hard-rock room and pillar mining and which was held in Polokwane during April 2010. The principal objective of the Best Practice Workshop was to provide a forum for mine operators and others in the industry interested in rock engineering safety in hard-rock room and pillar mining to exchange knowledge, practical experience, ideas, and innovations.

One of the key discussion topics held at this workshop was around best practice in respect of current bolting equipment and tendons to make the most impact on safe production. Room size and appropriate pillar size as a fundamental support design were discussed in another workshop. This workshop concentrated on future development in roofbolting practices and the selection and installation of support tendons. Three major focus areas were identified:

- What are we trying to support and with what tendons?
- How should we ensure safe production with:
  - fully mechanized bolting operations and
  - semi-mechanized bolting operations?

What are we trying to support and with what tendons?

The most important need in determining what requires supporting is to understand the hangingwall structure. The specific elements that require supporting are the inherent joint sets in the hangingwall, shallow dipping fractures usually associated with shear structures, and parting planes commonly associated with chromite bands. Typical tendon lengths are in the range of 1.6 m to 2.0 m.

Suitable support tendons for the joint sets are full-column resin bolts, hydro bolts, friction bolts, and mechanical bolts. There was some discussion about the suitability of the different bolting systems, but the general conclusion was that the best bolting system is the one that is correctly and consistently installed. Poor installation of even the best tendon system leads to an inefficient support system. Best practice is to install these shorter support tendons in a systematic pattern.

Support tendons for shallow-dipping structures and parting planes are typically between 2.5 m and 6.0 m in length – depending on how far into the hangingwall the structure or plane of weakness is located. Given that in these room and pillar mining operations stope heights are usually less than 2 m, it is necessary that these longer tendons should be cable anchors.

Long tendons should be installed by end-anchoring and tensioning the cable before cement grouting, which should commence as soon as possible after tensioning. Best practice is to determine the position of these structures by systematic longhole drilling and the use of borehole cameras. and then installing appropriate support tendons as required.

At the workshop there was a presentation on the use of appropriate blasting processes to effectively smooth wall blast and minimize the blast damage inflicted on the hangingwall. The introduction of smooth blasting practices would result in a safer working environment.

How should we ensure safe production?

The best way to ensure that no one gets injured in the bolting process is to ensure that no one is exposed to unsupported ground. This includes the process of 'making safe', and to this end the use of hydro-scaling was briefly discussed in the workshop.

In fully mechanized support installation operations, for best practice the operator should be under supported ground and at a safe distance from the bolting operation or under a custom-designed and built safety canopy.

In semi-mechanized support installation operations, for best practice temporary support in the form of mechanical props and areal support must be erected before permanent support installation commences. The mini bolter must be operated remotely and drilling and the bolt installation completed before moving to the next bolt.

When installing long tendons to specifically support, an identified structure best practice requires that either of the conditions above for fully mechanized or semi-mechanized support installations must prevail. When installing long tendons in a systematic pattern, best practice is for them to be installed concurrently with the shorter tendons.

To ensure competent grouting, best practice requires the mine to implement a grout management system to ensure that grout is not used beyond its expiry date.

All the above are for steady-state mining conditions. When the face has stood for a period of time, additional care must be taken to assess and support the ground.

Driving influences behind today's mechanized bolting

Reliable roof support in underground mining operations is essential for worker safety and the mining operation as a whole. Rock reinforcement methodologies through the ages have gradually moved away from the conventional 'hand-held' type bolting operation to the use of mechanized mining equipment used to complete the entire roof support or rock reinforcement process.

The initial major drivers for bringing mechanized mining equipment into the equation were based on improving productivity and overall production targets, and reducing dilution. However, the spin-off in improved operator safety was soon evident.

Legislation and regulations around mining are becoming more stringent as time passes. It is because of this growing need for a safety-conscious environment in underground mining, and because of the development and evolution of mechanized low-seam mining in the South African platinum group metals and chrome mining industries, that the need for low-profile mechanized bolting equipment arose.

Developing mechanized roofbolting in particular can address and optimize the following factors, which can improve safety, reduce dilution, and improve reliability and production, in underground mining:

- Improved ergonomic designs and man-machine interface considerations offer a more comfortable and less strenuous working environment for the operators, reducing fatigue and allowing for ultimately increased productivity
- Continuously minimizing the time that the operator needs to spend in unsafe working areas, through mechanizing the bolting equipment, thus improving the safe working conditions even further and improving productivity
- Precise drilling patterns and superior installation techniques of mechanized bolting rigs ensure safer advances as well as consistently higher bolting quality, resulting in safer roof support and improved production capabilities
- Drill hole deviation and misalignment can be avoided through proper feedback controls.

Semi-mechanized roof bolting[3]

Sandvik introduced the first low-profile, semi-mechanized roofbolting machine into the South African mining industry in late 2001. Although the benefits were huge, challenges still lay ahead. The operator had to go into the hazardous area at the front of machine, and although there is a protective bolting head canopy for the person installing the bolt and resin by hand, the operator is required to work close to moving parts. The operator has to couple drill steel during drilling, insert resin cartridges, and insert the bolts, which involves lifting heavy material, working near moving parts, being exposed to fumes, and standing in awkward positions.

There is now, however, mechanized bolt tightening, which allows for increased integrity of the installed bolt, thus reducing the effects of human error by ensuring consistency with every bolt installed.

In today's mining world, it is also a fact that most incidents do not occur while people are operating equipment, but while they are just moving around the machine, working area, or simply getting from one place to another. In order to reduce the number of operator-related incidents, the drive to take the operator out of the hazardous environment became more prominent, and so the development of the mechanized roofbolter began. Maximum safety for the operator and productivity are main guidelines in the development of this product family.

Mechanized roofbolting[3]

The DS210L-M, as depicted in Figure 2, is a low-profile, fully mechanized, single-boom bolting machine designed to work in headroom of 1.6 – 5 m. It allows access into workings with low-profile headings as well as higher-profile areas, and is designed to enable the operator to install resin or mechanical end-anchor bolts from the safety and comfort of the operator's compartment, or any other remote position away from the dangerous, unsupported area.

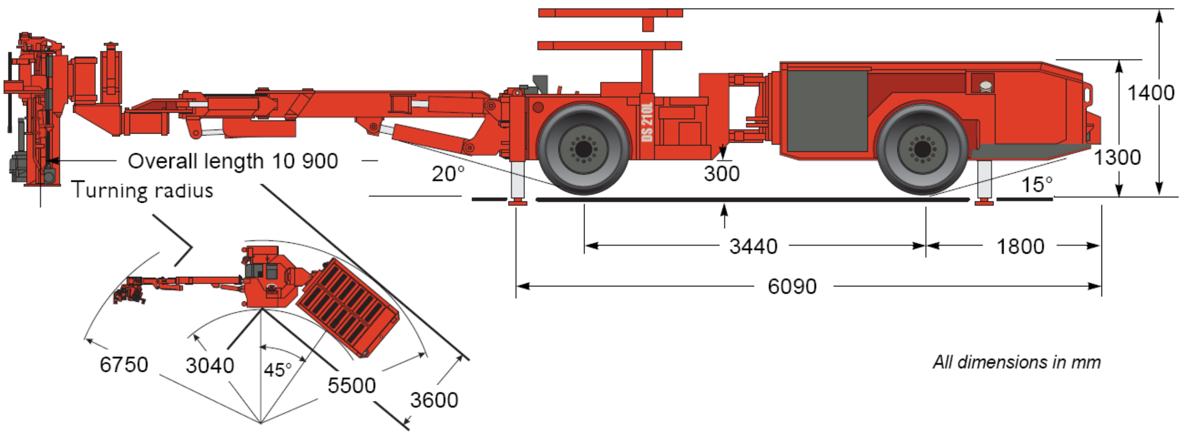

Figure 2-Mechanized roofbolter (DS210L-M) specification

The bolting cassette, as seen in Figure 3, can hold five bolts, thus eliminating the need for the operator to have to go to the front of the machine to load resin and bolts after every bolt installation. Due to the usage and safe location of automatic resin injection, operators are also no longer exposed to fumes. These rock support drill rigs make underground excavations safer places to operate in. Advanced bolting mechanizations eliminate human error and ensure total reliability and integrity of every single bolt installation. The full bolting cycle can be conducted safely by one operator.

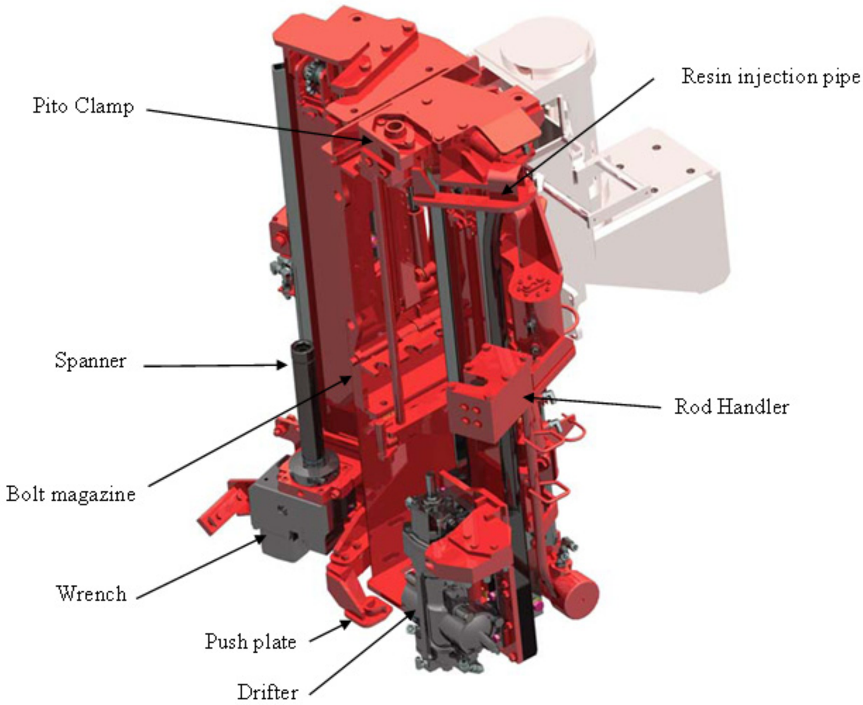

Figure 3-Current mechanized roofbolter (DS210L-M) bolting head

With the aim of continuously improving operator safety, technology advances are always being explored to minimize operator exposure to possible hazards. In-house design and development, and working together with a number of mining houses as partners, forms part of the process of continuously improving operator safety and improving machine reliability and productivity. After a lot of development work a new mechanized bolting carousel (TULPM turret), has been designed and manufactured, and will go into operation in the next new few months.

The main reasons for this development work were to:

- Enhance productivity
- Improve sidewall bolting
- Improve safety during bolt loading.

The resulting solutions and benefits include:

- Improved sidewall bolting with good pre-tension of the bolts inside the magazine, as seen in Figure 4
- A system that can stop the feed if the forks are not back in their correct position, to avoid collision between pusher and forks. A desired torque of 384 Nm can be reached
- Operators will be able to check rotary pressure on one existing manometer to ensure correct bolt torque
- The injection tube can be more easily maintained with better set-up of valves
- Filling the magazine will be possible without hydraulic movement, therefore ensuring that the machine is fully isolated and that there will be no unplanned movements. An operator will be able to load the five bolts into the carousel easily and safely, as depicted in Figure 5
- The bolting spanner will be modified to improve sidewall bolting
- A more robust control sticker material will be employed
- Sensor and electrical wiring protection improvement
- A new polyurethane block system will be implemented, to replace the current spring tensioning system, to push the bolts kit to prevent the bolts from falling out.

Figure 4-Mechanized roofbolter (DS210L-M) with new TULPM turret

Figure 5-New TULPM bolting turret

Mechanized bolting – the way forward

With continued demand from regulatory authorities, mining houses, and OEMs to ensure safety in underground mining operations and from mining companies to increase productivity, rock reinforcement roofbolters have had to prove that they can meet the challenges of underground hard rock support needs in mines – safety, bolting quality, reliability, performance, and flexibility. Protecting the operator and the machine and maximizing production are top priorities, with a fundamental focus on safety and ergonomics, including reduced vibrations, ease of ground-level service, improved lighting, soundproofing, and superior operator comfort.

Although the supplier of equipment can design mechanized equipment as innovatively as possible, maximizing performance, while simultaneously trying to eliminate any safety-related hazards as much as humanly possible, the reality remains that operators are human and mechanized equipment cannot be considered foolproof, as human error remains and will always play a significant part in the cause of incidents.

Although original equipment manufacturers can continuously attempt to make machines safer and more reliable, but are not able to fully remove the human factor from the equation, a 'zero harm' solution can never be found. This philosophy in itself is what drives the mining industry towards furthering mechanization and ultimately automation.

Safety as a priority

Safety will remain the first and foremost consideration when developing new technologies and is the foundation platform for all design principles. It is fully understood, and expected, by all in the mining industry that should a new product enter the market, it is required to be safer than the previous. A result this focus has revealed itself through the many partnerships between original equipment manufacturers and their customers, the end users.

Mechanization and automation in a mine are synonymous with improved safety. Mechanization focuses on removing the operator from the unsafe, hazardous working areas, improving the efficiency of the bolting process itself, and ultimately increasing productivity. Automation can be attributed to additional controls and sensors, proximity detection devices, as well as a meticulous focus on the design process whereby attention is paid directly to the human-machine interaction.

Further safety considerations of these technologies are found in reducing the strenuous demands on an operator; by incorporating mechanized machinery into every mining process the physical requirements to complete the job are lessened. This results in a workforce operating within their capabilities, which ensures better concentration levels, safer completion of work orders, and of course fewer injuries due to heat exhaustion, fatigue, and over-exertion. An additional benefit of this is that it allows employers to further equalize their workforce gender representation, since meeting high physical demands is no longer a prerequisite to being a successful operator.

Skills shortage is a challenge faced by all in the mining industry today. Mechanization and automation can also aid in reducing the required skills levels and thus allowing far more lower-skilled workers the opportunity to work and develop, while still obtaining the same level of output.

The future of mining can expect to see further improvements in all of the above, with significant safety advantages due to the further development of all of the current mechanized features currently available, as well as the introduction of new technological advances. Some of these will be outlined in the following section.

Automation, productivity, and system flexibility

The evolution from conventional mining to mechanized mining will inevitably continue to the point of semi- and fully-automated mining systems. Automation of a mine or a process has an earlier prerequisite in mechanization. The future of automated mechanization in mining will yield many benefits, such as better planning and control of the mining process and hence significantly reduced costs, which will be elaborated on in the remainder of this section.

By narrowing the focus of mine automation to mechanized- and automated roofbolting there are many apparent competitive advantages, but none more important than removing the workers from inadequately supported rock, particularly while disturbing it with rock drills. The majority of all mine-related accidents (and more importantly fatalities) occur in the danger zone where the hangingwall is unsupported or is in the process of being supported. It stands to reason that by addressing this danger the entire mine will become a safer environment, remembering that today's unsupported hangingwall will be tomorrows 'ceiling' under which everyday operations take place.

As already stated, the automation of the bolting process removes the operator from the dangerous mine face as the operator can now manage the process from a remote location, preferably under a canopy with falling object protection structure (FOPS) certification. It also allows for more consistent bolting, which will ensure the bolt integrity. The advantage of this is that all the pressures and relative bolting angles during installation can be calculated and measured to ensure an optimal and consistent rock reinforcement process. It also creates a scenario whereby data-logging could create a recorded history of the mine's roof support should a safety audit take place. This integrity is achieved in part by the pressure measurement during the rock drilling and bolt torqueing processes, but also by a resin timer that will ensure proper setting and anchoring of the roof support.

Ensuring that the process of drilling and bolting is followed as per its prescribed requirements makes the process entirely objective, rather than subjective. It also allows an otherwise ordinary or inexperienced operator to produce results expected of an accomplished miner.

A further challenge confronting the industry is that of illness. The Chamber of Mines has estimated that AIDS has a prevalence of between 25 per cent and 30 per cent in the mining industry. This, combined with the effects of tuberculosis and other incapacitating medical conditions, equates to a dramatic drop-off in productivity.

To further compound the problem the human capital expense increases year-on-year at a greater rate than that of general inflation, as illustrated in Figure 6, meaning that it will cost a mining operation more and more each year to mine less and less. Introducing modern solutions for a combination of modern problems will allow an operator to perform more proficiently; in a comfortable, ergonomically safe, and far less hazardous environment; with less effort, thus ensuring costs and productivity stay, at the very least, in balance with past and current expectations.

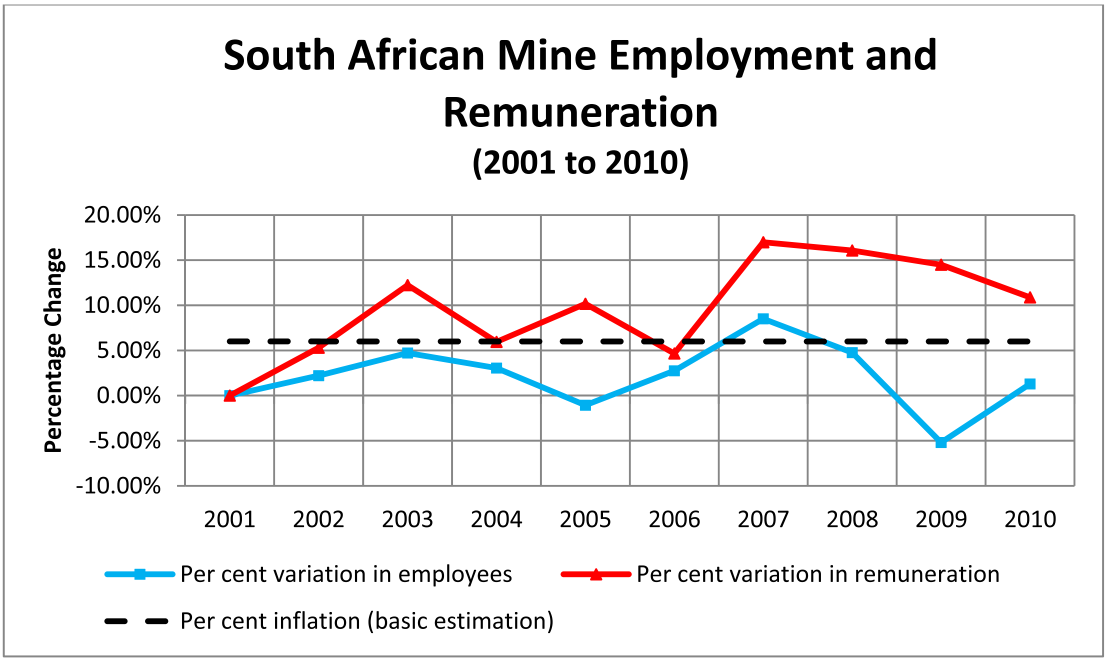

Figure 6-Human capital costs in the South African mining sector, 2001–2010[1]

Based on the The Best Practice Industry Workshop[2] on Rock Engineering in Hard-rock Room and Pillar Mining the future development that was discussed, as a wish list from the group, include the following:

- Remotely operated and preferably fully automated, universal cable bolter able to install a full range of tendons from 1.6 m up to 6 m in length. Installation to consist of drilling, tendon installation and anchoring, tendon tensioning followed by full column grouting.
- A way of non-destructively identifying what length of tendon has been installed and the integrity of the full column grouting process. Identification to be with an indicator on the bolt or alternatively a separate instrument.
- A long tendon that absorbs energy while yielding.
- A resin grout that does not require spinning to activate

Condition monitoring equipment and management systems is yet another message that came through from the group, who stated: 'You can't manage what you can't measure'. Mapping to understand what you have got is important. However, best practice measurements should include the systematic use of borehole cameras to physically see what structure is in the hanging wall and to clearly identify beam thickness. This information will then be used to update mine isopachs, clearly showing the position of planes of weakness on a regional scale. Additional tools are 'fall of ground lights' inserted in the hangingwall and telescopic 'Rockwatcher' closure meters to monitor ground movement. There is also some potential for ground penetrating radar, but the ability to use the information obtained in a real-time sense is compromised by the fact that the interpretation of the data can take up to three weeks

A final point regarding the future of mechanized mining lies in the natural evolution towards full automation of the bolting process. By combining the original pre-planned bolting patterns, computing power, modern sensor, mine planning, and environmental rendering abilities, as well as the mechanical brute force of the mechanized bolting equipment it could be possible to authorize a command from a remote location and execute a perfectly safe bolting process in the precise manner that any geologist would prescribe.

Concluding remarks

As the mining industry trends towards an age of mechanisation and automation, so the OEMs attempt to stay on the forefront of technological advances to provide the end users with the best possible solutions to optimise their mining operations, while keeping the workforce as safe as possible.

Human error is a common denominator in many accidents and incidents, which has led the technology drive to move away from conventional mining toward mechanisation. Mechanization and the possible automation of the bolting process would mean less human error and therefore fewer incidents. Although we have a long way to go towards achieving a 'zero harm' working environment a step in the right direction is to continuously make the mechanized equipment as efficient as possible while simultaneously drive development towards autonomous bolting operations.

From the best practise workshop2 facilitated by the Centre for Mechanized Mining Systems in February 2011, it was evident that current best practise in roof support is to install tendons between 1.6 m and 2 m, in length. This includes full-column resin bolts, hydro bolts, friction bolts, and mechanical bolts. The conclusion was that the best bolt is the one that was correctly and consistently installed. It was also recognized that for parting planes, the best practise was to install support tendons of 2.5 m – 6 m in length. Since room and pillar mines are typically 2 m and less in working height, it stands to reason that these tendons should be cable anchors.

Current research programmes in industry are focusing on remote examining of the environment, thereby creating a hazard map of the rock support environment highlighting potential areas of weaknesses that need to be supported before allowing workers into the area. This research could also be expanded into finding a way to effectively input the mine's bolting pattern into the remote machine, with the aim of autonomously bolting the hangingwall while ensuring bolting integrity

Although safety principles in mechanized mining are an evolving science, proper application of its principles can achieve benefits that are significant and immediate.

Despite the advances that have been made in rock support and reinforcement technology in the recent past, the focus on ultimately reaching a totally safe mining environment will keep driving technology. The mining industry, together with the equipment suppliers, will have to work together on developing solutions with the aim of achieving the ultimate target of 'zero harm' and creating working environments that are safe for all.

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