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The implementation of mechanized breast mining and the development of XLP equipment

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In 2006 at the Platinum Conference Pickering and Moxham presented a paper 'The Development of XLP Equipment and the Implementation of Mechanized Breast Mining'. This paper continues where that one left off and delves into more detail about the application of XLP mining equipment and some of the particular equipment constraints that applied to the development of the XLP equipment. The emphasis is on the underground operation of the XLP equipment and the development of suitable mining methods.

Application of XLP equipment

Underground trials have two main components; firstly is the need to demonstrate that the equipment carries out the function that it was designed for and secondly that the mining method employed is adequately productive.

The Low Profile equipment had mainly been used in a room and pillar mining layout and at an early stage it was decided that the XLP fleet would be used in a similar layout. Initial trials were using the equipment for room and pillar mining. Some of the early problems encountered were related to blasting and a full advance of the face was rarely achieved despite the input of 'blasting engineers'. Room and pillar mining has a relatively large number of faces and moving equipment from one short face to another consumed a lot of production time. The tipping points for the LHDs were often 60 to 100 metres away from the loading point and it was soon realized that the constricted mining height limited tramming speeds and equipment productivity; this was the biggest draw back of room and pillar mining. To make this even more complicated there were three different XLP room and pillar mining trials going on at the same time.

The choice of mining method and the application of the equipment were equally problematic, probably even more problematic than the equipment issues. This is probably because the technical issues can be seen and understood by equipment designers and solutions quickly developed and tested. It is more difficult to bring about major changes in the mining layout expeditiously and this was coupled with a lack of mechanized mining expertise that was available to design optimal layouts to maximize the potential of the equipment.

Attention was then focused on a mining layout that has a closer relationship to conventional mining. Longer panels cleaning into a gully with rock movement in the gully with larger, more traditional LHDs; these would tip onto belt conveyors. Thus, the merits of on reef mining with no footwall development would be realized; extraction ratios would improve and the mining sequence was more easily understood. The layout is called Mechanized Breast Mining and is shown in Figure 1.

Mechanized Breast Mining - then

Mechanized Breast Mining was described as follows:

- Carry the reef access on the reef horizon, rather than in the footwall. The major benefits are that we obtain current information on the orebody and the excavation pays for itself. The major disadvantages are that the excavation has to follow the reef and is not suitable for traditional rail bound transport. To cater for reef variations and the need for water drainage this excavation has to be substantially above strike. Access dimensions will be determined by the equipment used, typically 3.5 metres wide and 1.7 metres high on the down dip side of the gully
- Make the faces as long as is practical given the constraints of face drilling equipment and minimum pillar spacing. The face drilling constraint is a function of shift time and equipment drilling rate. The maximum skin to skin dimension between pillars is currently about 33 metres, there has been good experience from Union Section over the last twenty years that these pillar dimensions and the use of elongate support elements provides practical and safe mining
- Make the extraction ratio as high as practically possible by minimizing the ore left in pillars. Work by CSIR for

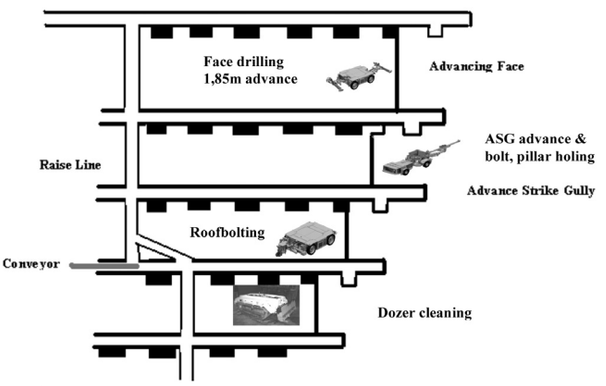

Figure 1. Mechanized Breast Mining

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PlatMine has shown that grout packs can be used to replace pillars. With advance orebody information is it practical to use ore loss from potholes as regional support, grout packs for areal support and roofbolts for face support?

- Assuming a mining process that allows two blast per twenty four hours, then a minimum of three stope faces are required; one to support, one to drill prior to blasting and one to clean. In practice, to accommodate the ground loss due to pot holes and other discontinuities there should be at least four and preferably five faces per equipment fleet
- Roofbolts are installed as face side support, leaving an open area between the face and the first row of elongates or grout packs of five to ten metres
- The advance strike gully is carried between five and eight metres ahead of the panel face. Gully roofbolts are installed after the roof bolt holes have been drilled with the Axcess Gully Rig and then the face is drilled by the same rig. Where necessary this unit also drills the down dip sidewall to create what will be the pillar holdings as the down dip face advances. This procedure ensures that ventilation is kept along the face. The Axcess Rig is shown in Figure 2
- At Karee Mine, in the Merensky reef, face drilling is 1.9 metres in length and advance per blast is 1.85 metres
- A large portion of the reef is blasted into the reef gully and the balance is pushed into the gully by the remotely operated bulldozer. The rock in the gully from both the face blast and the gully blast is loaded by the 777 LHD and trammed to the conveyor loading point. The conveyor tipping point is advanced after every sixty metres face advance
- Conveyors are installed every fourth gully and the LHD loads from the three faces above and the one face below the conveyor. To provide access to the loading point the stope width is opened out to a height of 1.7 metres and a width of four metres in the raise line, using the XLP face rig. Following the second blast in this higher section the broken rock is leveled by the bulldozer and the next round is drilled at the normal stope width of 1.2 to 1.3 metres
- After completing their face activities, the face drill rig and roofbolter are returned to the top of the panel, back along the gully, down the raise, along the gully and into the lower face. When reaching the bottom of the section the units are loaded onto a skid and dragged to the top of the series of faces by the 777 LHD. The cycle is then re-started.
- To minimize equipment lost time it is imperative that the cycle of activities is maintained.

Mechanized Breast Mining - now

With time reality is a little different than that described nearly three years ago and different mining companies have adopted different layouts to deliver substantially the same results. Figure 3 shows the panel layout adopted by Anglo Platinum.

The major constraint in this layout is the skin to skin spacing of 25 metres that result in a panel length of only 21 metres. However, this fits in well with the three shifts per 24 hours practiced at Waterval. Good aspects of the layout are the wide clearances at the face supported with roof bolts that permit the bottom eight metres of rock to be blasted into the gully and the balance of the blasted rock to be distributed over the roofbolted area such that the dozer has easy access and easily cleans the face. The gully is carried as an advance strike gully and that does lead to some congestion as gully advance and face advance have to interact continuously.

At Lonmin the stope layout as shown in Figure 4 is employed

Figure 2. Axcess Rig for Gully development

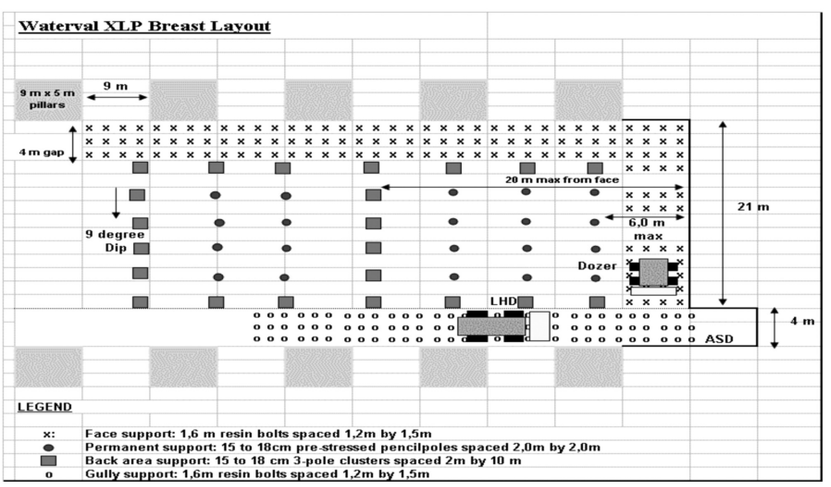

Figure 3. XLP Mechanized Breast layout at Waterval

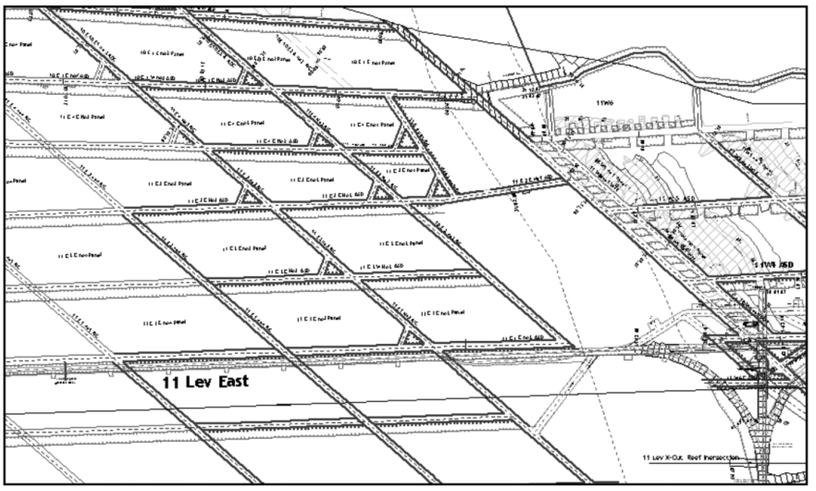

Figure 4. XLP Mechanized Breast layout at Lonmin

Table I
The trial XLP mechanized Breast at Waterval

Equipment rating	Planed performance	Actual Feb-Sept 06
Drill rig – holes drilled/shift/rig (rated - 40 holes/hr) (1.5 min/hole; 1.3 m/min)	126 holes/face/shift (21 m face/3.2hrs)	114 holes/face/shift
Roofbolter – 1.6 m bolts/shift/bolter (rated - 6 bolts/hr)	25 bolts/face/shift (21 m face/4.1hrs)	23 bolts/face/shift
Dozer – tons cleaned/shift (rated - 31 tons/hr) 180tons/face blasted – 40% throw blasting (72 tons) = 108tons/face/shift	108 tons/face/shift (21 m face/3.5hrs)	102 tons/shift (21m face/2.0 hrs) 36tons/hr
LHD – tons loaded/shift/LHD (rated - 25 tons/hr) 180 tons/shift blasted + 65 tons dev/shift blasted = 245 tons/shift / 2off LHDs = 123 tons/shift/LHD	123 tons/shift/LHD (Face+ASD/4.92 hrs)	130 tons/shift/LHD (Face+ASD/4.6hrs) 28 tons/hr/LHD 3.2t bucket factor 8 trips/hr
Axcess dev drill rig (ASD) (Raise) Total 2.87 m/shift/4 m = 72% x 4.28 = 3.08 hours/shift Bolting - rated 10 bolts/hr (ASD) (Raise) Total 15bolts/shift/1.9hrs = 72% x 1.9 = 1.37 hrs/shift Total drilling and bolting	39 holes/shift –1.62 hrs 34 holes/shift – 1.46 hrs Total ASD/Rse - 3,08 hrs 6 bolts/shift – 0,72 hrs 5 bolts/shift – 0,65 hrs Total ASD/raise -1.37 hrs 4.45 hrs	80 holes/shift 2,8 hours drilling 13 bolts/shift 1.2 hrs bolting 4 hours drill and bolt

In this layout the grid of strike and dip gullies is predeveloped as shown on the left of the figure and mining then takes place as a separate activity as shown on the right of the figure. This layout has some obvious advantages in that stoping and development are now separate activities that do not interfere with each other. The second main advantage is that the predeveloped grid provides information on the orebody and makes planned ore extraction a reality, the size and extent of potholes and other geological anomalies is known before stoping starts.

XLP equipment performance

The trial XLP Mechanized Breast at Waterval was based on three by eight hour shifts per day and an effective equipment available time of 6.2 hours per eight hour shift. Hole length drilled was 1.95 metres and advance per blast was 1.94 metres. The key results are shown in Table I.

The final comment from Anglo Platinum was that a 'Full suite of XLP (Drill Rig, Bolter and Dozer) & LP (Axcess Rig, LHD's) equipment operating in a Breast mining layout was trialed at Waterval Central Shaft Strike 4 East as from November 2005 up to November 2006. The scope of the trial was to determine the potential performance and operating costs of a Mechanized XLP Breast mining method as a guide for future roll-out potential at Waterval and the rest of the Group. The trial objectives were to deliver XLP production at a rate of 2400m²/month, stoping width of 1.20 m, tramming width of 1.41 m. The XLP Breast mining trial was successful, all the planned safety, productivity and cost objectives were achieved.'

Underground lessons

Different mining companies see the application of XLP mining equipment in different ways, in the 2006 paper it was stated that 'The choice of mining method and the application of the equipment were equally problematic, probably even more problematic than the equipment issues. This is probably because the technical issues can be seen

and understood by equipment designers and solutions quickly developed and tested. It is more difficult to bring about major changes in the mining layout expeditiously and this was coupled with a lack of mechanized mining expertise that was available to design optimal layouts to maximize the potential of the equipment.' There is no reason to believe that this is not still true today.

Equipment development

During the last few years that XLP equipment has been operating underground there have been numerous comments about how the equipment should have been designed. This section of the paper expands on the thought processes within Sandvik that have led to the specific equipment on sale today.

Mining width

Today it is generally accepted that the minimum height that XLP equipment will operate in is 1.2 metres. The initial target for XLP equipment was a stoping height of 1.1 metres. This was interpreted as 1.1 metres plus or minus 10% giving a minimum stope height of one metre. Clearance under the machine was set at 150 mm and 150 mm was assumed to be adequate for clearance above the machines. Thus the height of the machines above the footwall was set at 850 mm. The designers designed and delivered to these constraints with the top of the Sandvik face drill rig being only 820 mm above the footwall. So, if the machine does not get stuck on the footwall with only 150 mm clearance, why is it necessary to introduce greater clearance between the top of the machine and the hangingwall? What was not considered was that the rock engineers would use bolts that stuck out about 100mm from the hanging—thus reducing the clearance. The use of alternative bolting systems such as full column resin grouted rope anchors or hydrabolts would enable the minimum operating height to be reduced; again an issue of optimization of equipment and other aspects of the mining method rather than equipment specific issues.

The bolt example shown in Figure 5 is a Hydrabolt specifically designed for installation in narrow stopes. The metal tube expands under water pressure and grips the rock along its full length. For installations where the stope height is less than the bolt length the bolt is bent to allow installation. With the end inserted into the hole the operator then bends the bolt straight and completes the bolt installation. Minimum bolt size is 26mm diameter and it can be installed into a 28 mm diameter hole.

Maybe a resin grouted bolt correctly installed is better than a Hydrabolt—maybe a Hydrabolt correctly installed is better than a resin grouted bolt as typically installed. The lesson here is that it is not always necessary to invent new technology. An appropriate solution can often be provided by available technology.

Bolting

Bolting is currently regarded as the slowest ship in the convoy of the XLP mining fleet. Depending on the bolting pattern used and the length of the panel it takes approximately 40% more time to bolt a panel than to complete face drilling. It is worth while following the development of the bolter to see how the requirements and the product have changed.

The first XLP bolter was fitted with the HLX1 drifter. This drifter is approximately 600mm long and to drill a 1.3 metre long hole suitable for a 1.2 metres bolt in a 1.1 metre stope height required the use of five extension steels. Collaring was with a 30cm drill rod used to drill a 20cm hole, then four extension rods of 30cm each were used to drill about 20cm each to deliver a 1.4 metre hole. Bolting rate for 1.2 metre end anchored bolts was less than four bolts per hour. Figure 6 shows the front end of the Sandvik XLP Bolter fitted with the drifter and bolt spinning head.

Even before the first prototype XLP Bolter was manufactured it was realized that it was necessary to develop a different and entirely new drifter for this application and work was commenced in 2001. The new drifter was initially called the Ultra Short Drifter, but this was subsequently changed to the HSX drifter to match the Sandvik naming policy.

Figure 7 shows the size if the HSX drifter.

The height of the drifter from the bottom to the lower end of the shank adaptor was only 287 mm with the width and breadth being 284 mm and 237 mm. Quite a remarkable achievement to package 4kW of power into such a small envelope. An additional feature of the HSX was that the torque of the drifter had been substantially increased so that resin bolts could be spun and tightened and a separate spinning head was no longer required.

By now bolt lengths had increased to 1.5 metres and it took six minutes to drill and install an end anchored coupling bolt; the time to install a 1.5 metre resin bolt was seven minutes. However, operator skills were poor and total bolting rate was still around four bolts an hour.

Other improvements to the XLP Bolter included;

- The fitting of a rod clamp to assist in extension drilling
- fitting a canopy to provide protection for the bolt installer
- a radio remote to replace the cable remote
- changes to the drill feed mechanism to provide higher drilling force to match the HSX drifter, plus
- changes to the drill steel, especially the drill steel coupling.

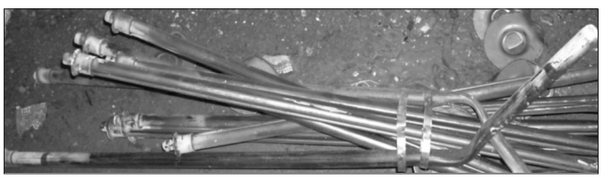

Figure 5. Hydrabolt designed for narrow stopes

Figure 6. First Prototype XLP Bolter circa 2002

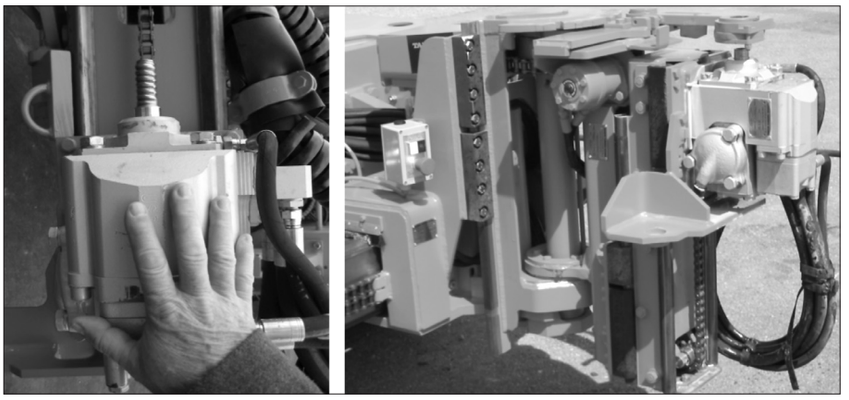

Figure 7. New Sandvik HSX Drifter circa 2003

During 2007 an average of 23 bolts were installed on each of two shifts a day for a period of one month. The total cycle is made up of 6.34 minutes to drill, insert resin and install the 1.6 metre bolt; and 2.3 minutes to reposition the bolter to install the next bolt. A total of about nine minutes per bolt and an average installation rate of six bolts per hour. Still some way off the required target of achieving ten bolts per hour.

Drilling relatively long holes in a restricted environment is a time consuming activity due to the large number of extension steels required. The traditional way to couple steel used in rotary percussive drilling is via a threaded connection. The size of the threaded couplings necessitates that the hole drilling size is not less than about 33 mm; this is fine for end anchored bolts but not ideal for resin anchored bolts – the large hole size consumes more resin and the large hole/bolt annulus inhibits good resin mixing. See Figure 8.

One way to reduce the time used to change steels is to simplify the steel coupling mechanism. The first design used a simple hex coupling shown in Figure 9. The coupling works well when new but wears rapidly and becomes difficult to disconnect. The high wear rate also leads to a high drilling consumable cost.

The current solution is seen to be the development of an entirely new coupling configuration referred to as a 'figure 8' or 'infinity' coupling. This coupling is shown in Figure 10. The shape is more difficult to manufacture but the wear surfaces are substantially larger and hence more wear tolerant, early indications are that the increased life will result in the consumable drilling cost being reduced by about two thirds of the consumable cost of hex drilling. The actual collaring, drilling and rod extraction time for a 34 mm diameter hole 1.6 metres in length has reduced from four minutes for the hex steel to three minutes for the infinity coupling. However, the main advantage from introducing this change in the drill steel is that it is now possible to drill 28 mm diameter roofbolt holes. For a 19mm diameter roof bolt a 28 mm hole will further reduce the drilling time as well as reduce the amount of resin and lead to near optimal resin mixing.

The next issue is that installing a 1.6 metre long bolt in a stope height of 1.1 metres means that the bolt must have a coupling. Mechanical end anchored bolts are drilled at about 36 mm and the coupling is a female/female coupling. Changing this bolt to full column resin grouted creates difficulties for inserting the bolt with a large coupling that has to be pushed into the resin grout package and a larger hole has to be used to accommodate the coupling element. It is proposed to resolve this issue by using the coupling bolt shown in Figure 11. The female coupling part of this bolt has an outside diameter that is similar to that of the ridges on the re-bar.

Figure 8. Examples of R23 coupling drill steel used to drill approximately 1.6 metre long hole

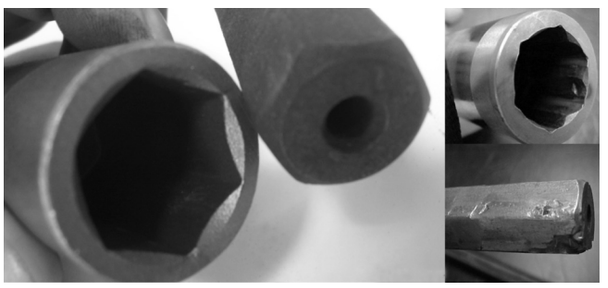

Figure 9. Simple hex drill string coupling—new and worn

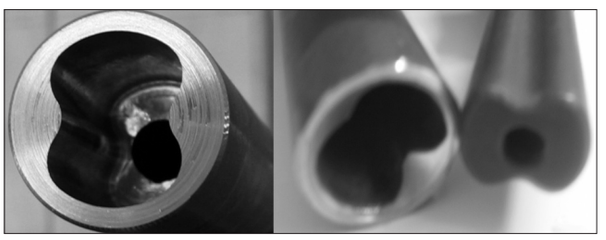

Figure 10. Figure 8 or infinity drill steel coupling

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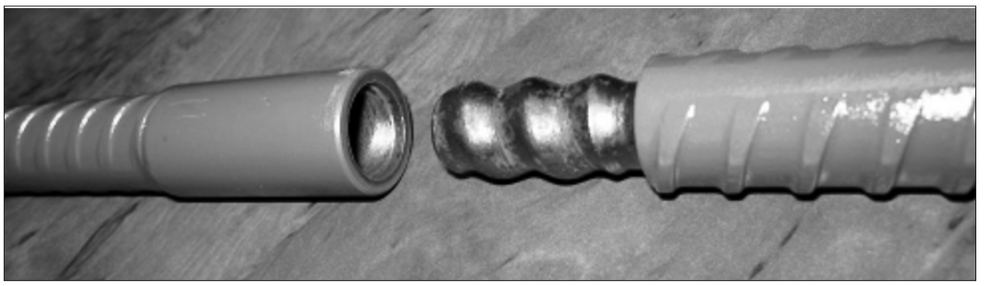

Figure 11. Coupling bolt

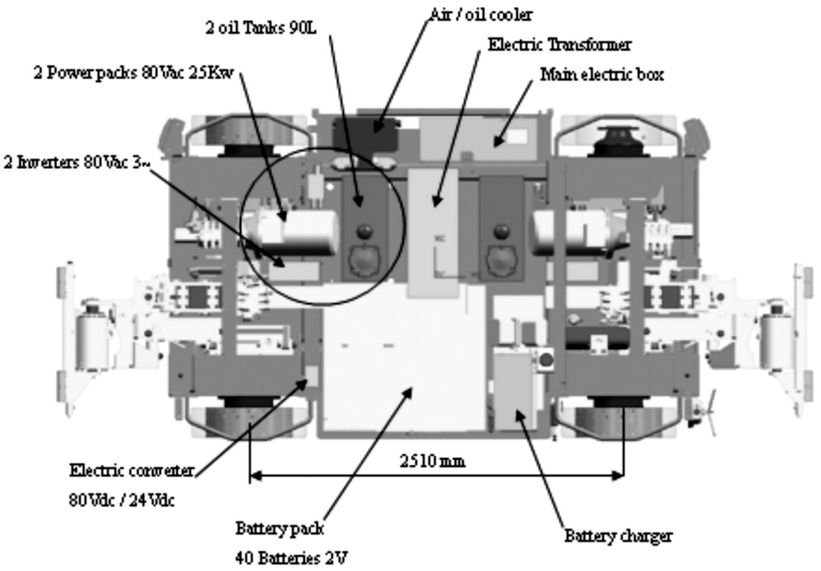

Figure 12. Conceptual design of XLP drill rig with on-board battery power

The combination of the new drill steel and the new bolt will be a faster bolt installation rate combined with a lower resin cost to deliver higher productivity at a lower operating cost. Exactly what should come out of a well run development project. This has been achieved by developing:

- A special drifter that minimizes the number of extension drill steels required to drill a hole substantially longer than the stope height
- A drill steel with reasonable life suitable for drilling a 28 mm diameter hole
- A coupling bolt that fits the smaller hole.

Drill rig mobility

Both the face rig and the bolter are powered by electric motors and to enable them to move around the stope the power cable must be plugged into an electricity distribution socket. This is fine when the machines are operating in the stope but require excessive cable handling when moving from one panel to another—or from the panel back to the workshop.

During the design stage one aspect of mobility that received thorough attention was the size of the machine – specifically the cross section of the machine. When the footwall is exactly parallel to the hangingwall the cross section of the drill rig is not an issue. However, given the reef rolls and variability of dip the smaller the rig cross section the greater the mobility and the lower the stope height in which the rig will successfully operate. The face drill rig has a wheel spacing of 1 900 mm, overall length of 4 260 mm and a width of 2 200 mm.

Consideration was given to equipping the drill rigs with a self powering unit to enable it to move from panel to panel. Two different powering options were considered:

- An on board diesel engine that would increase the length of the drill rig by about one metre. This was rejected because of the increased length and the additional pollution from the diesel engine
- Installing a battery pack on board. This increased the length of the drill rig by 510 mm and was considered a much better option. Batteries require less maintenance than a diesel engine, generate no pollution, are more compact and could be charged while the drill rig was operating in the stope. Figure 12 shows the conceptual design of the face drill rig fitted with batteries.

Following discussion with the customers neither option was implemented as the increased size and reduced mobility of the drill rig was considered to be very unattractive. Work is now proceeding with the development of a separate carrier that will transport the drill rig and the bolter along the various strike and dip drives and will be used to launch them into the face and to recover them after they have completed their work in the stope face.

Comments/conclusion

Current conventional mining practice is acknowledged to employ relatively low skilled workers with corresponding relatively low pay packages and the accident and fatality statistics show that mining is a dangerous occupation. Despite the slow start to the introduction of XLP mining there is no doubt that the mining companies see mechanization as a substantially safer option for mining narrow reefs; both due to the reduction in the number of employees exposed to a dangerous environment and the safer operating environment that mechanization brings. Skill levels to operate and maintain mechanized equipment are higher and thus pay packets are also higher.

Successful mechanization of the narrow reefs typical of South African gold and platinum mining has been difficult and the current experience demonstrates that there is no simple solution waiting in the wings. The development of an appropriate mining process and appropriate equipment is an iterative one requiring 'big picture' vision, dedication and commitment to succeed on behalf of equipment suppliers and mining companies.

Technology development is not normally the limiting factor—after all if we can send men to the moon surely we can mechanize narrow reef mining. For example, there are a number of novel rockcutting machines on trial in the platinum mines with the objective of introducing true continuous mining without the inhibition created by blasting and re-entry periods. It is the authors' opinion that it is the change in mining processes and mine management that is a bigger challenge.

This paper has only identified some of the development processes and additional mining methods and equipment are sought to handle the steeper dipping orebodies as well as the extremely narrow orebodies.

Rod Pickering

Consultant, Sandvik

Rod grew up in Yorkshire and was educated in Dorset. He started work in 1960 when he joined Shell Tankers as an engineering apprentice. There he completed a training programme for merchant navy engineering officers. He had nearly three years of general maintenance in marine and steam raising plant. He learnt the basics of engineering from the ground up and today he is still a competent fitter and welder. In 1965 he enrolled at Brighton College of Technology where he obtained a BSc Honours in Mechanical Engineering. He arrived in South Africa in 1969 and started work on the mines as a Junior Engineer with Union Corporation. There he obtained his Mechanical Engineers Certificate of Competency. He moved from the mines and worked in maintenance, sales and construction for a period of six years. His last position was that of contracts manager on the Pelindaba uranium enrichment site. He joined the Chamber of Mines Research Organization in 1977 and the highlight of his time with COMRO was being appointed director of the Stoping Technology Laboratory with the responsibility to develop ways of mechanizing the narrow reef hard rock gold mines. It was while at the Chamber that he gained a good understanding of the opportunities and the barriers inhibiting change in the mining industry. In late 1996 he started his own business combining his knowledge of mechanization and mining. His first task was to investigate the practicality of using a Tunnel Boring Machine in a deep level gold mine. Since 1998 his major client has been Sandvik Mining and Construction

Where his role is that of Manager of Strategic Projects with special responsibility for narrow reef and narrow vein mining throughout the world. His objective is to develop new mining processes in collaboration with customers. These new mining processes will use existing technology, or new technology that has to be specially developed. The ultimate objective is safer more cost-effective mining. The last few years have resulted in Low Profile and Xtra Low Profile mining equipment as well as a novel rock cutting machine. Rod is passionate about working within the mining industry to introduce change. His dream is to be part of that change that will transform the narrow reef hard rock mining industry and South Africa. He has been a Fellow of the SAIMM since 1985 and believes that it is important to give back to the mining industry

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