

A hard rock narrow reef mining machine—ARM 1100

K.A. MOXHAM
Lonmin Platinum

The ARM 1100 was described in a paper presented at the 6th International Symposium on Mine Mechanization and Automation in September 2001. It started operation underground at Rowland Shaft in early 2002. This paper covers the results of those trials that resulted in more than 1 100 square metres of UG2 being mined.

Introduction

During the last thirty to forty years, major efforts have been made to mechanize the South African hard rock mining industry. However, most if not all the narrow hard rock reef mines where 'trackless mechanized mining' was introduced have reverted back to conventional handheld mining. This trend continues to this very day with two major issues not yet being resolved:

- Dilution and
- Change management.

Dilution has been and will continue to be the demise of any attempt to mechanize the mining method. In the higher reefs where the envelope is in excess of >1.8 m mechanized mining has become the option of choice. While most of the gold and platinum mines in South Africa have very narrow reefs (<1 m) that are not conducive to 'off the shelf' copper or coal mining equipment. This implies that new equipment making use of tried and tested components needs to be creatively and innovatively adapted for this restrictive environment.

The second issue is the ability to successfully implement new and alternate mining methods. These new methods make use of machinery and equipment that are technologically advanced. Mine managers, and engineers need to accept the fact that new approaches and an alternate methodology is now required. A systematic approach, which holistically views the environment, needs to be adopted, functional boundaries must be challenged, alternatives sought and skills developed to sustain this new way.

Our current mining methods are still dependent on blasting techniques to break the rock. The cyclic nature of mining by blasting places severe constraints on the rate of face advance that can be achieved and consequently the utilization of the invested capital. For narrow reef hard rock mining to break out of these constraints and to really make progress in the 21st century it is necessary to follow the lead set by the soft rock mining industry. In the underground coal mining industry, coal cutting has been proven to be a most cost-effective solution; thus in narrow reef hard rock mining the future must be based on the development of non-explosive methods of rock breaking that in turn are integrated into continuous mining systems. Non-explosive so that the mining operation can be conducted on a continuous basis, with no delays for the

removal of blasting fumes. This change has vast potential in asset utilization and return on investments. An alternate mining method such as rock cutting will also deliver many additional benefits such as:

- Safety—stope conditions without blast induced damage
- Safety—removing people from danger
- People—reducing hard arduous forms of work
- People—attracting young talent to the industry
- Dilution—defined stope width control

Lonmin mechanization and automation strategy

Lonmin Platinum has embarked on an aggressive ten-year vision to re-engineer its mining operations. A mechanization and automation strategy has been formulated to transform the mining process into the 21st century. Broadly, the strategy focuses on three main areas:

- The worker
- The workplace
- The manager.

Within Lonmin Platinum mines, alternate mining methods are being sought to re-engineer the traditional handheld explosive based cyclic mining method to that of a non-explosive and continuous nature. One of the pillars of the mechanization and automation (M&A) strategy being pursued is continuous mining and the vision of non-explosive based mining. The move from cyclic explosive based mining to that of continuous non-explosive mining methods has been the dream of many mining engineers. Much of the vast Bushveld Complex has favourable dipping orebodies, mostly in the range of 8 to 13°. This, when compared to the steeply dipping orebodies of the South African gold mines, the bushveld invites the potential to mechanize the stoping process.

However it is Lonmin's view that the orebody will always dictate the mining method, hence there will always be a place for the most appropriate methodology.

Project history

In early 2001 Lonmin Platinum, Voest Alpine and Sandvik Tamrock entered into a partnership to co-develop and trial the narrow reef miner. The machine was designed and manufactured and surface tests were completed in October 2001. The prototype ARM 1100 was then commissioned at

Rowland Shaft and underground operations started in February 2002.

The trial had two major objectives:

- To demonstrate that the machine could cut hard rock within a confined space and
- That the machine performance and cutter life could ultimately deliver a viable alternate stoping method.

The depth of cut largely dictates the production performance of the machine and that in turn is controlled by the rock failure mechanism. By varying depth of cut and penetration rate an optimum performance has been determined in the UG2, given the torque and force limitations are a product of machine size. It has been shown that the machine can complete an advance of 850 mm in sixty minutes. Production is estimated to be between 6–8 000 tons per machine per month working a three- shift 22-day cycle.

The undercutting process generates loads on the cutter bearings and cutter carbides that are markedly different from more conventional hard rock cutting. This initially caused carbide and bearing failures. After an extensive testing programme carbide button rings shrunk onto the hub have successfully cut in access of 50 metres advance with only 5.5 mm of wear. To achieve economic carbide life an advance of 100 metres is the target.

Rock handling in the face and from here to the interface into the mine infrastructure has received major attention. Mechanized drilling and installation of roof bolts have provided the instope support.

Theory of disc cutting

Mechanical rock failure is a complex process influenced by nearly all rock physical and geological rock properties. The dominant mode of failure is still the subject of much research. One aspect shared by all the theories is the existence of a zone of highly crushed rock material beneath the cutter tip prior to chipping. As the cutter penetrates the rock, a pressure bulb or crushed zone is formed due to the extremely high stresses generated in the rock under the tip of the cutter. The pressure in the crushed zone causes tensile cracks to initiate and propagate into the rock mass. If the stresses developed in the crushed zone are sufficiently high, one or more cracks extend far enough to reach one of the tensile cracks developed from an adjacent cut, or alternatively a free face. In conventional disc cutting, rock failure is in the form of chipping. Figure 1 shows this

process. In undercutting the crack propagation is to a free face and rock fragments generated are substantially larger.

Narrow reef miner's specification

Evaluation of the initial results from the pre-construction phase led to the conclusion that the reef miner should have the following generalized specifications:

- All the cutting discs would be mounted in the same cutting plane
- The reef would be cut in an undercutting mode, thus minimizing the power and cutting forces and maximizing the chip sizes
- The effective undercutting depth was estimated to be between 50 and 60 mm
- Machine stability and stiffness was essential, thus,
 - the machine must be staked while cutting,
 - the cutter boom must be as short and stiff as possible,
- The machine will not be fitted with crawlers and will walk in the stope using its staking system
- The machine must be capable of cutting its own entry into the stope
- The machine should excavate the maximum amount of reef from a single set-up
- The machine in operation must be flexible enough to follow the major reef undulations
- All rock cuttings must be removed from the immediate cutting area and then transported out of the stope.

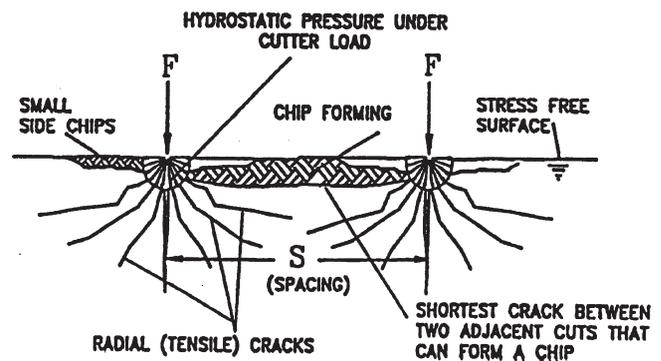
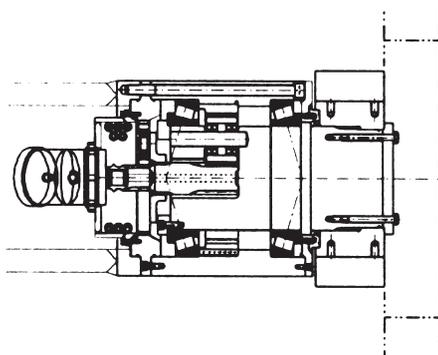
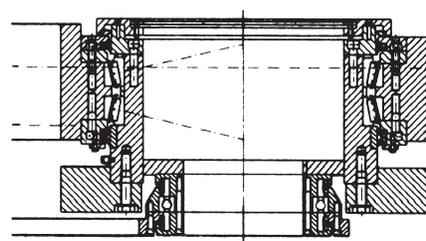


Figure 1. Theoretical rock breaking process for conventional disc cutting



Cutter gear box from roadheader



Turret high load bearing from roadheader

Figure 2. Examples of existing technology used in the machine design

Additional features of the narrow reef miner

This generalized specification was fleshed out and the reef miner conceived is shown in Figure 3 and has the following main advantages:

- The machine design was simple in concept and made use of tried and tested components
- The machine was easy to automate and this had already been done with other coal mining machines
- The machine consists of easily maintainable components with most of the main functions being driven by hydraulic cylinders
- Most importantly, because the total system is simple and flexible, the machine can be accommodated in a wide variety of mining layouts.

Underground trial

Rowland IShaft

Figure 3 shows the ARM 1100 test site at Rowland Shaft. The cutting trial commenced in January 2002 on 25 Level with the first cut made in February 2002. The first six months of the trial was spent on testing different cutting set-ups and cutter discs and a total of 25 metres were achieved in the period up to 17 July 2002. At this point the trial was stopped and new cutters were ordered and modifications to the machine were undertaken. Cutting recommenced in the first week of October 2002 and a further 40 metres were cut in the period to the first week in November 2002. By the end of January 2003 the machine had cut a total advance of 100 metres.

The trial team consisted of the following full-time personnel:

- Artisan/operator - Western Platinum Mine
- Technicians - VAB
- Technician - Sandvik Tamrock

The structure of the UG2 orebody at the trial site is Lonmin's deepest, a UCS of ± 120 Mpa, extremely hard and

obviously very abrasive. This therefore provided an extremely difficult test for the cutting ability of the ARM 1100.

The ARM was installed on the east side of a raise-winze connection and is cutting from the solid face to the free face in the raise. The cutting plan is to cut up-dip for a distance of approximately 70 metres and then turn the machine around and cut down-dip for 80 metres. Once completed, the ability of the machine to take a blind cut in a strike direction will be tested. Figure 6 shows some early pictures of the machine underground.

Data collection

The first two weeks of testing was spent largely on determining best slewing forces, depth of cut, cutter penetration, cycle times, etc. Figure 7 is a typical example of the data collected for every cut of the machine.

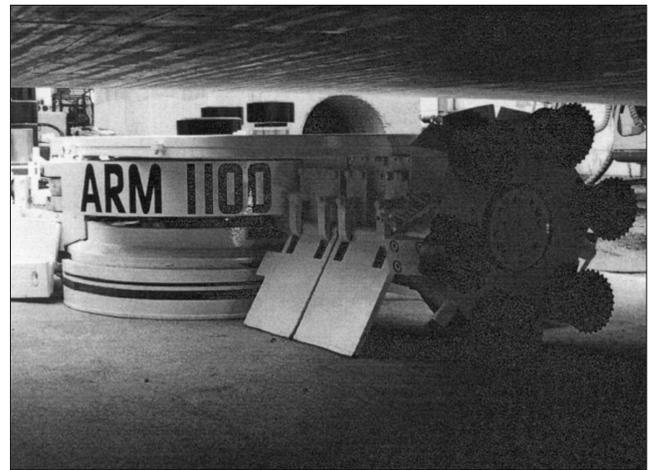


Figure 3

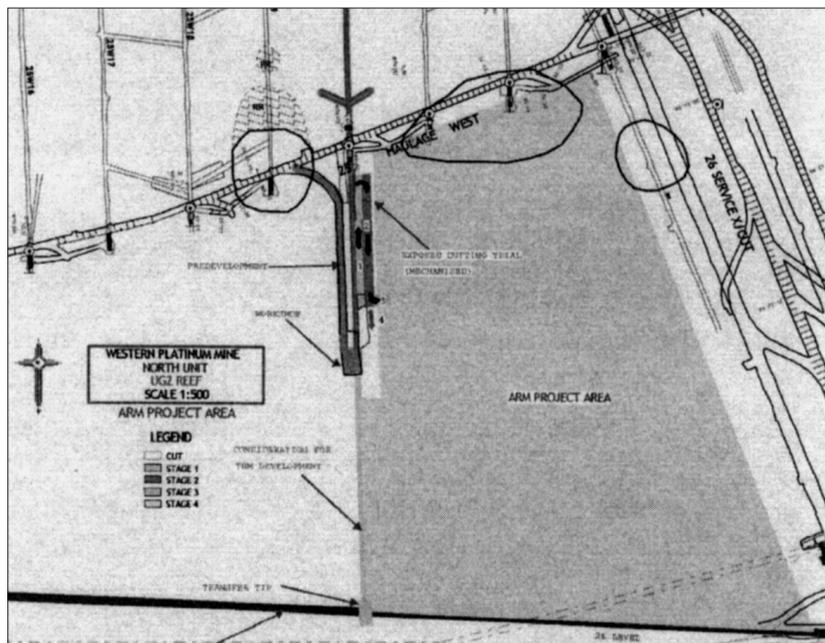


Figure 4. Rowland Shaft ARM 1100 test venue

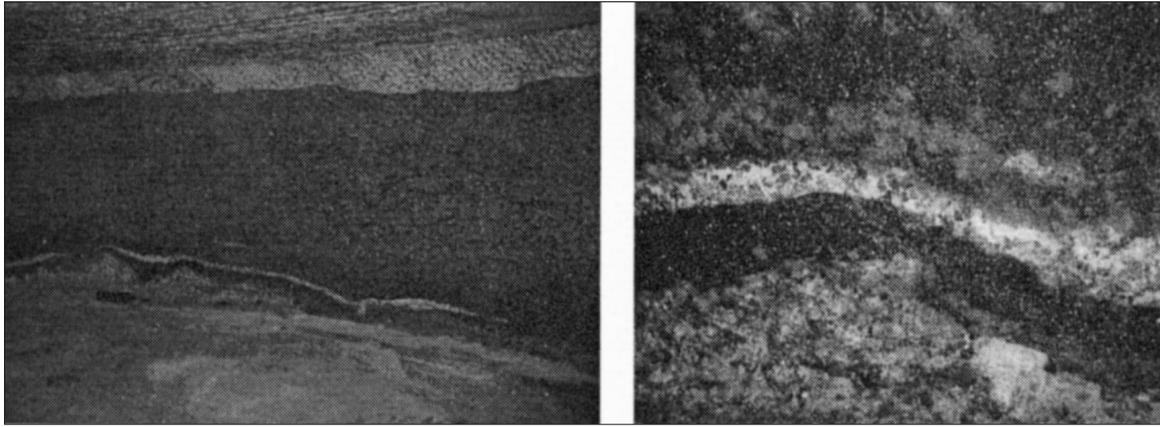


Figure 5. Typical cut face and detail of footwall contact

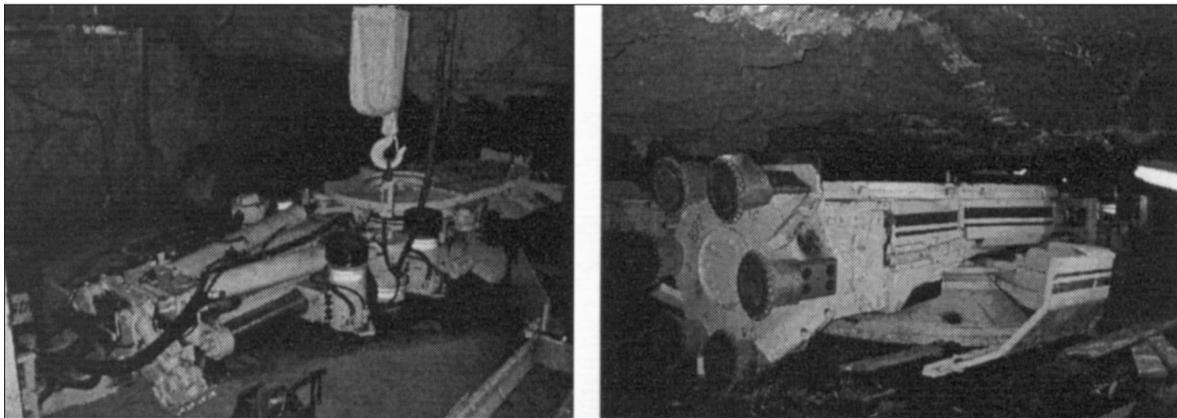
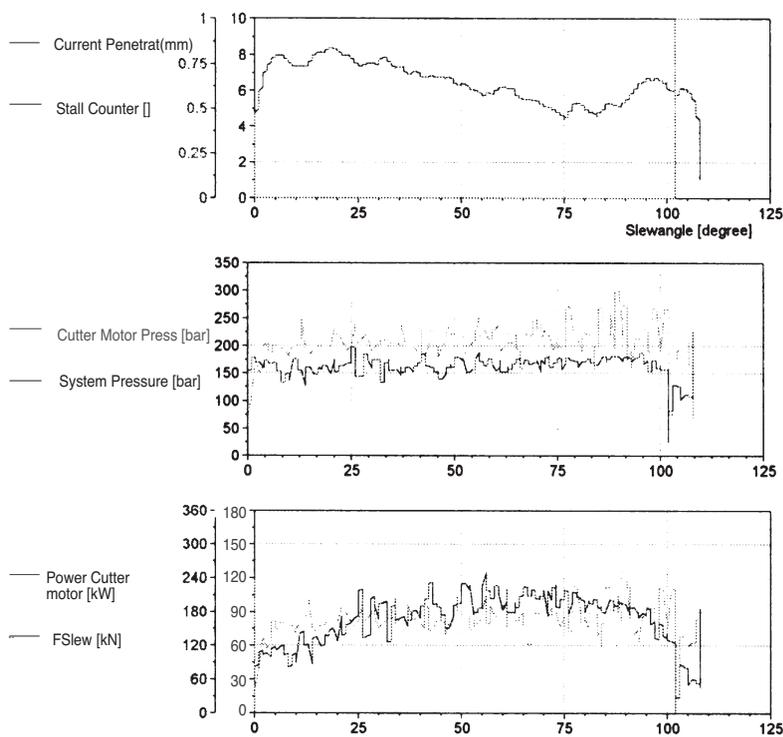


Figure 6. Assembly of the ARM 1100, launching the machine and cutting into the raise



Cutting Parameter :

Type of Disk	7 x Ring Conical 20deg
Type of Bearing	MK I mod 10 deg
Gripper pressure [bar]	240.0 (constant)
F_Slewing [kN]	230.0 (constant)
Penetration [mm]	9.0 (constant)
Type of Penetration	always constant

Results :

Sampling Rate [Hz]	5.57
Measurement Duration [sec]	9
Sump Position [mm]	755.0
Cutting Time [sec]	143.0
Real Sump In Depth [mm]	46.0
Cutting Angle [degree]	107.0
Number of Stalls []	1
Mean Penetration [mm]	6.28
Mean Slewing Force [kN]	170.0
Mean Power of Cuttermotor [kW]	83.3
Cut starts at Index 186 and stops at Index 981	
Cut starts at 33 and stops at 176 seconds.	
Cut starts at 1.0 and stops at 108.0 degrees.	

Figure 7. Typical machine and cutting data collected for each cycle of the machine

Cutter configuration

After operating parameters were set different cutter disc designs were tested. Cutters tested were manufactured with varying angles of attack, different bearing designs and different cutting edges, as shown in Figure 8

After extensive testing of various disc cutters, a best design was selected and it was decided to manufacture according to this design with varying tungsten carbide grades on the inserts.

Cleaning system modifications

During this time the cleaning mechanisms were evaluated and modified to improve the effectiveness of rock removal from the face. Early examples of the different rock removal system are shown in Figure 9.

Narrow reef miner performance

Over 500 cuts have been recorded to date, by means of the on-board data-recording system, and evaluated. Information has thus been collected of the following:

- Cutter arm slewing force
- Cutter head power consumption
- Cutter arm slewing speed and mean penetration
- Advance per cut
- Number of cutter head stalls.

This information obtained to date has been used to determine the most suitable cutting geometry and the determination of optimum cutting parameters.

With the cutter arm force set at 230 kN the cutter head does not stall however, cutter head penetration is limited by

depth of cut. Figure 10 is an example of the detailed analysis carried out and shows how penetration and depth of cut are related for different carbide and cutter configurations. However, the fracture mechanics of the rock breaking process limit the depth of cut that can be achieved.

Figure 11 shows how undercutting with the current cutter design becomes ineffectual as depth of cut is increased.

Cutter performance

During the trial period 11 different cutter types and two different cutter heads have been tested and evaluated. The cutters are the single most important and least understood component of this project. Furthermore the cutters and the associated cutter life are vitally important to the economic viability of this alternate method. Cutter costs make up around 70% of the total costs per ton produced.

The cutters tested differed in three basic areas, these are:

- button orientation (15° and 20° degrees)
- shape of buttons/cutting edges (conical buttons, chisel type buttons, steel rings)
- bearing configurations
- angle of cutter axis.

To date, 15° conical button cutters have performed the best in terms of wear, performance (Performance being defined as cutting rate) and material produced (more chips and fewer fines). Steel-ring cutters performed better and produced a bulkier sized final product but wore out extremely quickly.

Figure 12 shows how rock fragmentation is affected by cutter type.

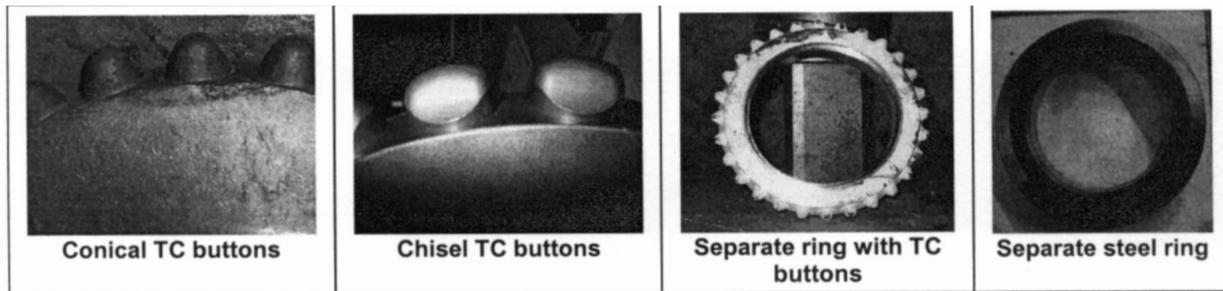


Figure 8. Different carbide profiles tested on the machine

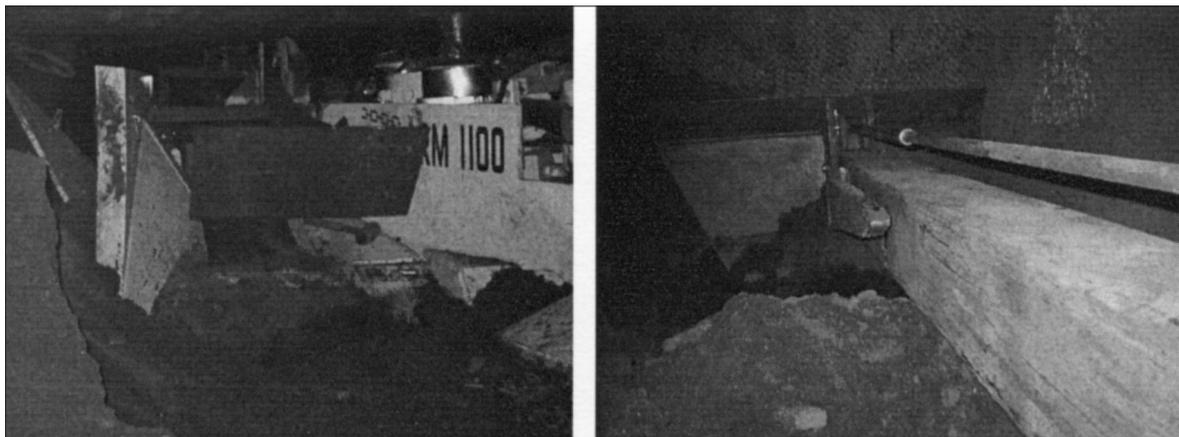


Figure 9. Scoop arm used to load cut rock onto the belt conveyor

EFFECTIVE PENETRATION / DEPTH of CUT
 The effective penetration reflects the sieving speed based on the 6 cutter cutterhead
 The 'set penetration' is 7 to 9 mm
 The effective penetration is limited by the max. Cutter arm sieving force of 230 kN

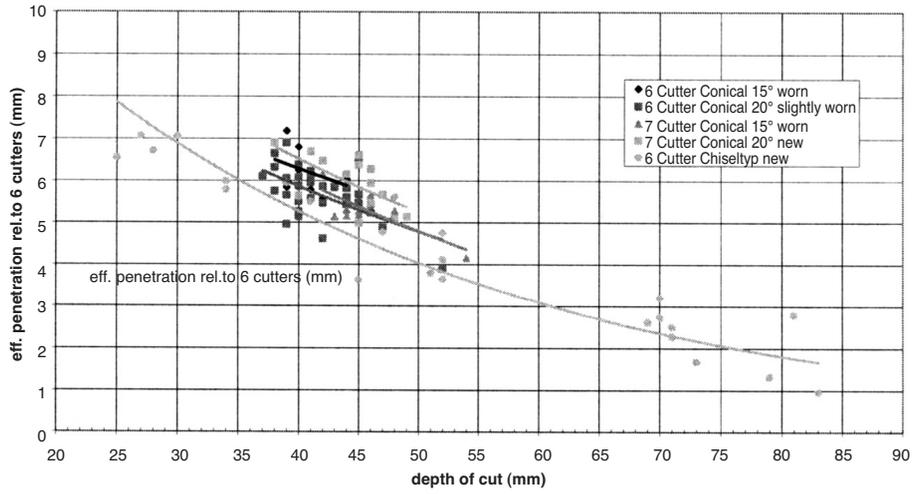


Figure 10. Effective penetration against depth of cut

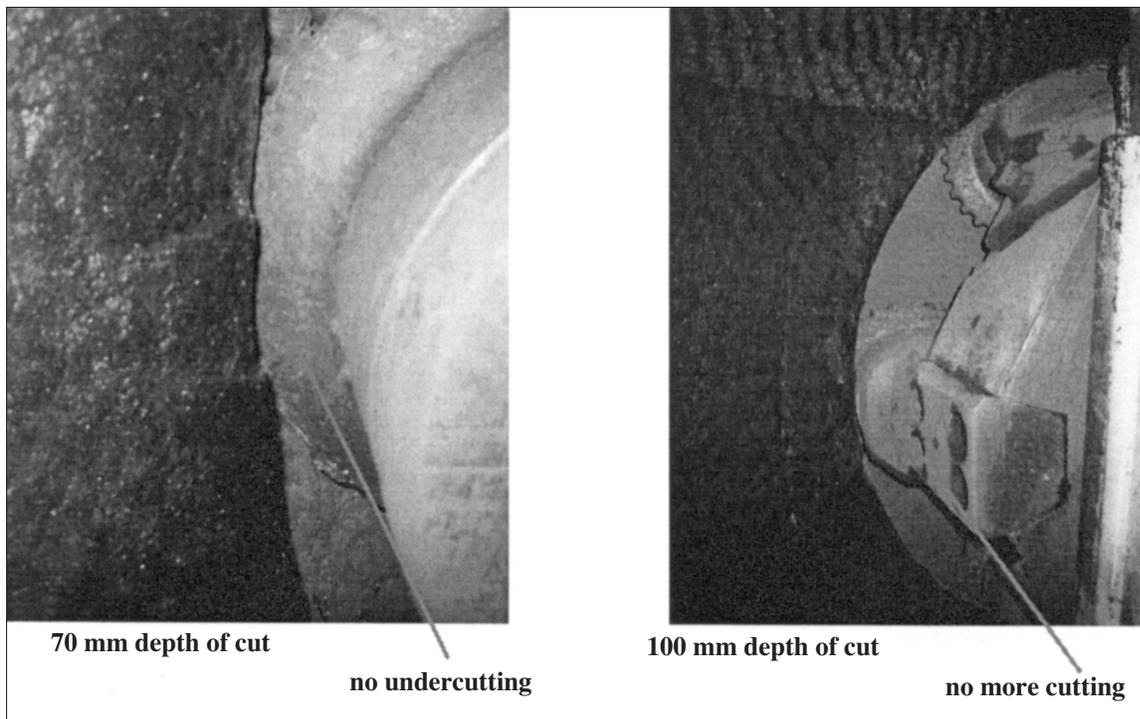


Figure 11. With increased depth of cut undercutting ceases to be effective

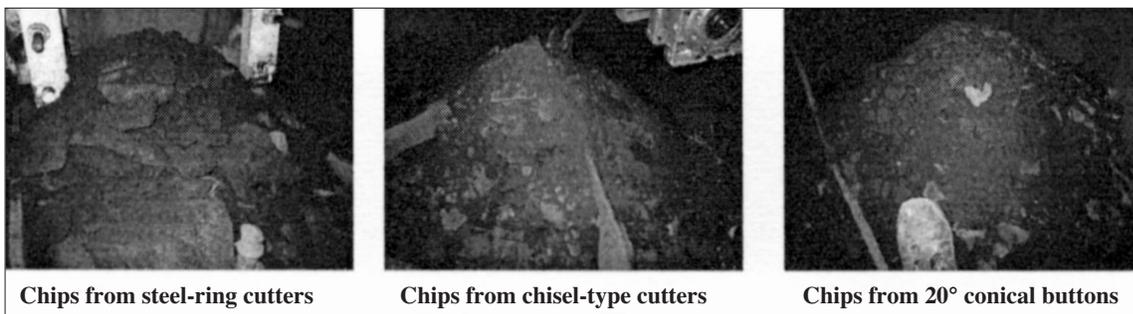


Figure 12. Rock fragmentation produced from different cutter configurations

A significant difference in chip size and consequently specific energy was realized from different cutter types.

- The biggest chips and lowest volume of fines was produced with the steel ring cutter
- The conical buttons generated the smallest chips and highest volumes of fines
- The chisel shaped buttons produced fragmentation sizes somewhere in between the other two cutters.

Cutterhead

The original cutter head was designed and manufactured with six cutter discs. It was determined early on in the trial that more cutters on the head will result in a smoother and more effective cutting process. A new cutting head was built and installed in the middle of July 2002 and it proved to be a better option with higher slewing speed and greater depths of cuts being achieved. Future generations of the machine will have to have an increase in installed power. This increase in available power will result in improved cutting rates and less grinding, resulting in lower fines' generation.

Cleaning process

From the outset the cleaning of ore away from the cutter head was identified as a major obstacle and indeed proved to be problematic. The main issues being:

- Cleaning of ore from the cutting path. Too much ore remained in the cutter path after completion of the cleaning stroke. This is demonstrated in Figure 13 below
- The ore remaining is subject to a regrinding action, resulting in high fines content.
- The cleaning arm which feeds the ore into the loading chute to the conveyor is inefficient
- The conveyor design is inadequate and results in excessive breakages. This is the result of both design (return pulley too short) and the accumulation of fines under the conveyor.

A number of changes was made to improve the situation, Figure 14 shows the general arrangement, and more changes are in the process of being made. These are:



Figure 13. Material left on the face after the cutter head has completed its cleaning stroke

- Installation of a new loading shovel and increasing the speed of the shovel
- An additional hydraulic pump was installed to enable the loading shovel to operate independently from the cutting arm.
- Manufacture and installation of new muck chute
- Loading plough at the end of cutter boom to remove ore more efficiently from the face
- Stopping rotation of cutter head during loading stroke.

General learning and cutter observations

The ARM cutting principle is based on the principle that the cutting action will propagate cracks and fractures in the rock along which the chips will break off. The nature of the UG2 reef however does not support the formation of fracture propagation, which results in relatively low cutting efficiency. The UG2 in the trial area is also of the hardest in the Bushveld Complex and better performance can be expected in softer UG2 ores and the more brittle Merensky reef.

Roof support

Currently roof support is being installed by hand. The necessity to have an integrated permanent roof support system was recognized early on in the project. With the availability now of a drifter small enough to operate in a 1.1 M stopping height it was decided to start immediately with design of an integrated bolting system.

Ore handling system

The cleaning system behind the ARM is another problem, which requires urgent attention. At the moment a ULP loader is being successfully used, this provides a flexible, reliable cleaning method however, a very expensive one.

Other alternatives are also being perused such as:-

- Vacuum system
- Mobile conveyors
- Shuttle cars

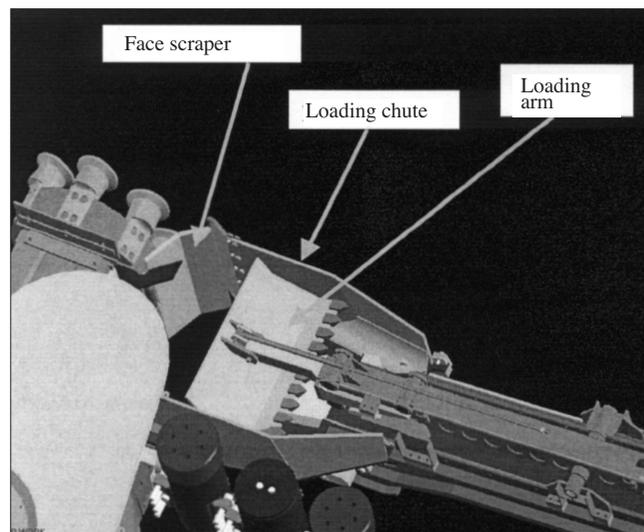


Figure 14. Modified conveyor belt loading

Narrow reef miner cutting performance (Proto-Type Machine)

The proto-type machine cut a total of 270 linear metres. It is undeniable that the fact that the concept was able to cut these metres there is renewed hope that this will become a viable alternative to current conventional drill and blast mining methods.

To this end, the first production machine (MK II) is currently underground and cutting at Lonmin Platinum's Rowland Shaft.

Acknowledgement

The author would like to thank the directors of Lonmin Platinum and the Sandvik Mining & Construction (SMC) for the permission to publish this paper.



Figure 15. The ULP loader in the cut stope

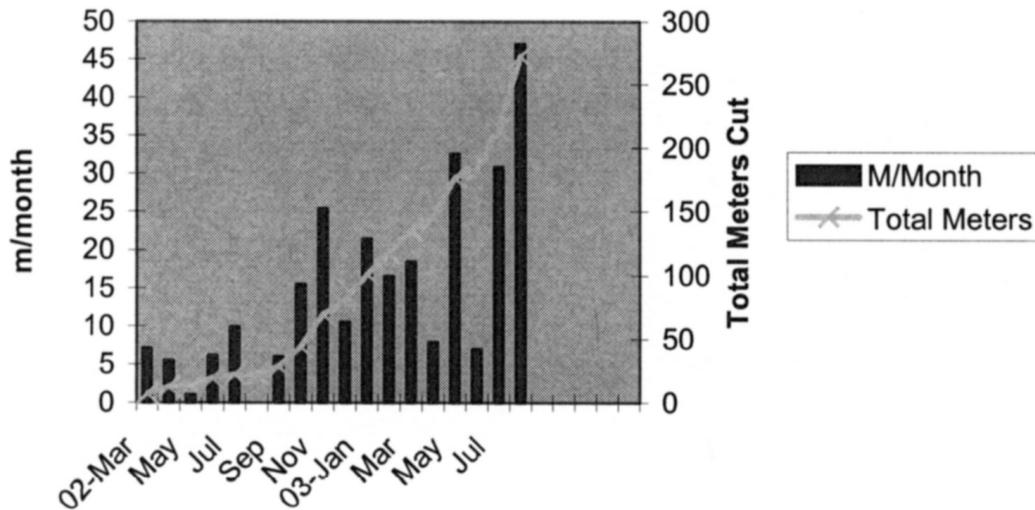


Figure 16. Prototype cutting performance