

## Development and implementation of an electrically-powered stope rockdrill for TauTona Mine

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### Synopsis

Environmentally-friendly, safe and cost-effective technology for stope drilling has successfully been introduced at TauTona mine. It has enabled the problem of inadequate compressed air pressure and its downgrading impact on production capability to be overcome. This paper traces the development process which culminated in the conversion of the entire stoping operation at TauTona to electric drilling. Background work which took place at other mines is also described. Statistics of performance improvements are provided.

### 1. Introduction

Holman's Silver series and the Seco S215 were drills that had a measurable impact on the South African gold mining industry. It is too soon to say whether Hilti will join those great names. However, there is no doubt that the introduction of electric drills into the harsh and unforgiving world of deep level gold mining is a significant development. History has shown that being the first to enter a new technology is no guarantee of long-term success. The pain and suffering which accompany the birth of anything new can deplete the energy of the innovator while at the same time creating opportunities for competitors to leapfrog him. In addition to commitment and enthusiasm, the innovator must therefore also possess, or have access to stamina and resourcefulness to overcome the unexpected difficulties which will inevitably arise. All of these were needed for the Hilti project.

Work in AngloGold (as AngloGold Ashanti was then known) on the possible use of electrically powered drills for underground use began in 1996, but progress was fairly slow during the first few years. However by the year 2000, the following statements left no doubt that senior management fully supported the initiative. Dick Fisher, who at the time was the Executive Officer responsible for Technology, Safety and Health, said: "Our company is strongly committed to developing and applying new technology as we see this as one of the chief ways to achieve our vision of a 21<sup>st</sup> Century workplace. We see the electric rock drill as having enormous potential for our mines and for other deep-level mines the world over. We are delighted that the project has progressed to the point that full-scale testing is under way. The initial performance indications are positive with our employees readily accepting this new technology." Dave Hodgson, recently retired from the position of Chief Operating Officer, stated that: "In South Africa, deep-level, hard rock gold mining is significantly constrained by the fact that for the most part, it continues to employ fifty year-old technology, epitomised in the hand-held (pneumatic) rock drill. The lack of innovation in production and services technology leads to pedestrian face advance rates, and contributes to the industry's less than proud safety record and slow cost control progress".

So there were stated the drivers behind the need for change, and the challenges which the electric drilling technology was intended to meet. It had to provide for improvements in safety and working conditions, increased rates of face advance, and improved cost control. All of the changes had to be welcomed by the work force.

By comparison to a pneumatic drill, the electric drill has the following advantages:

- It is significantly quieter and has lower vibration levels, making it a more acceptable tool from an ergonomic perspective.
- It has a lower rate of energy consumption because electricity is a far more efficient power source than compressed air.
- It can be used where compressed air reticulation is lacking or inadequate for pneumatic equipment.
- It provides for greater precision in positioning and control of the drill which brings benefits to the blasting activity and scope for productivity improvements.
- Visibility in the working environment is better because no fog is produced by the drills.
- Reduced fatigue levels on the drillers, while reducing risk due to shorter drilling time on the stope face.

It looked as if electric drilling had the potential to meet the challenges and requirements. This paper traces how that potential was realised. The joint resources of AngloGold Ashanti and the Hilti Corporation were

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brought together to achieve success in this project. AngloGold Ashanti has a well-known pedigree for innovation and development of technologies. Hilti is a world leader in power tools used in the construction and building maintenance industries. Between them, they have developed a drill which has a lower energy cost and which provides for better working conditions.

Statistics have been kept to a minimum in this paper for a number of reasons. Firstly, targets and actual performances are a direct function of local circumstances and corporate policies. Each application possesses a different set of these things. Secondly, some of the numbers relate to contractual agreements; again these are dependant on local circumstances, and each intended application is likely to arrive at a different conclusion. Where detail has been provided, it is in enumerating the principles and issues which needed to be addressed as part of the intervention. The many repetitions of breakdowns and failures have not been catalogued in a diary form; they have merely been referred to for information. Nevertheless, the amount of documentation associated with this project is considerable, and if greater detail is needed in any specific area, the author is prepared to assist in the fulfilment of requests.

## **2. Background**

### **2.1 The need for a change**

In 1996 the idea of using an electric rock drill underground was raised in AngloGold. Due to the condition of the compressed air and water reticulation systems in the mines, and the costs associated with their maintenance, some alternative energy source for rock drilling merited investigation. Miners are notoriously conservative, and change does not come easily to operations in the working face. It had taken several decades in the early years of the twentieth century for pneumatic drills to replace hammers and chisels for the creation of shotholes. While pneumatic rock drills are heavy, difficult to handle and utilise energy at an efficiency of only about 4%, they are reasonably reliable. The men who operate them carry a certain amount of stature among their peers. Any change to this part of the production process was going to have to address both engineering and social issues.

### **2.2 Review of alternatives and preliminary prototype**

The obvious potential alternatives to compressed air as an energy source are hydropower and electricity. Hydropower offers a higher drilling speed, but this is offset by high costs, potentially dangerous consequences from supply line failure and by a lack of existing infrastructure. Electricity would have to be used in close proximity to water if it were to be applied to rock drilling, but this is not a unique situation, and therefore it appeared to be a more promising option. Hilti were approached by AngloGold in 1996 to assess the feasibility of using electrically-powered tools in stopes and development ends for the drilling of shotholes. Hilti had a potentially applicable technology; however they had to establish the market potential and its likely impact on their profitability before embarking on the development work. The market research indicated that success in such a venture was likely to be profitable, and their agreement was obtained. Development work was conducted at Hilti's facility in Liechtenstein and a prototype was developed in 2000 which was tested at AngloGold Ashanti's in-house new technology department. Tests were conducted on surface, drilling holes into a norite block. The thrust provided by the in line drill rig was inconsistent, and this was the cause of drill steel failures. Also penetration rates were disappointing. So this first attempt proved to be unsuitable for underground conditions, and lacked adequate power. However, it did include many of the design concepts which contributed to the success of the operational version. Among these were the modular nature of the construction, and the electrical connections. An improved version was subjected to field tests. Kopanang Mine and TauTona Mine were involved to a greater or lesser degree. For a number of reasons, tests were discontinued at Kopanang Mine, and since mid-2003, the development work has taken place at TauTona.

2.3 Design concepts

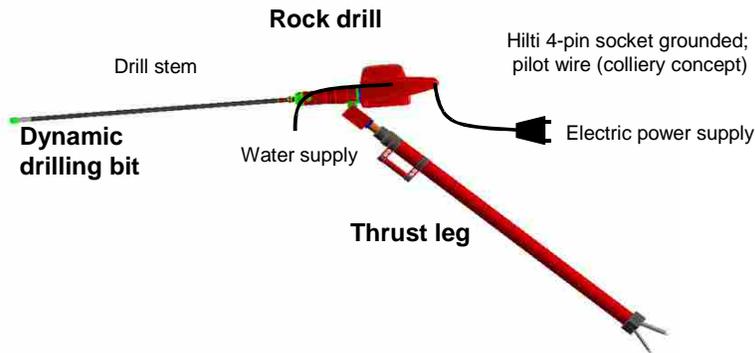


Figure 1. Components of the drilling system

The original system consisted of three main components; the rock drill, the thrust leg and the dynamic drilling bit. They are illustrated in figure 1. The rock drill consists of four modules (figure 2) bolted together for quick and easy maintenance. Downtime is minimised by merely replacing the faulty module and repairing it at a later stage. The modules are:

- main motor housing
- hammer mechanism
- electronics
- gearbox

They are sealed units to ensure that the water and gearbox oil cannot mix during operation, and that electricity is isolated from both the fluids.

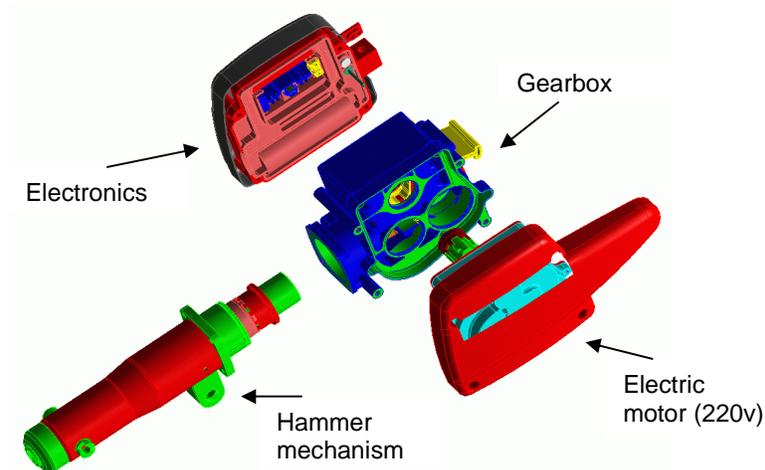
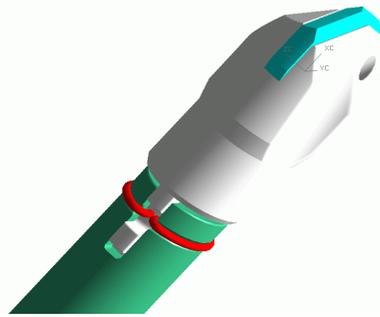


Figure 2. Modular design of electrical rock drill.

The water leg generates thrust and utilises the same water supply as that used by the rock drill for flushing the hole. The water also serves to cool the machine during drilling.

Hilti's original bit is known as a dynamic head, which allows axial movement through a clip which connects it to the drill stem. Energy is transmitted from the hammer mechanism onto the drill stem to the dynamic head. Hilti's own trials had indicated that this method provided an improvement of 30% over the penetration rate achieved with conventional knock-off bits. Figure 3 illustrates the dynamic head. As will be seen later, despite this apparent benefit, the clip-off bits lacked adequate robustness, and had to be replaced by knock-off bits during the Kopanang trials.



**Figure 3. The dynamic head.**

The electronic functions are:

- Frequency control of the motor.
- Running hours recording.
- Servicing requirement reminder generation.
- Electronic malfunction indication.
- Status of the machine (e.g. switched on/off) recording.
- Internal machine temperature measurement to eliminate possible damage due to overheating.
- Switches off the machine in the case of a malfunction.
- Detecting under and over voltage.

A four-wire individually screened cable supplies the electric motor. The fourth wire is used as a pilot wire. Its purpose is to monitor the earthing circuit while the machine is in use. It also disconnects the power supply when the cable is unplugged from the machine. The pilot pin inside the restraining plug is shorter than the other three to ensure that the power supply is switched off before contact with the other three pins is broken. This concept eliminates sparking when unplugging the cable.

### 3. Development of the electric rock drill for underground applications

#### 3.1 Specifications

Based on the shortcomings identified during the initial testing, modifications to the design were introduced. The specifications are listed in the tabulation below. Note should be taken of some of the salient features in the ergonomic and environmental fields; that is the noise level, sound pressure and machine mass; to see by how much these factors are improvements on the pneumatic drill.

Element	Value
Power input	1800 W
Voltage range	220 – 240 v
Current	13 A
Frequency range	50 - 60 Hz
Insulation class I	IP 66
Flame proof description	Eex Die I/IIB T4
Mass (estimated)	18 kg
Length x width x height (mm)	770 x 210 x 230
Impact energy	23 J
Motor speed	16000 rpm
Drill steel speed	250 rpm
Clutch Torque	80 Nm
Vibration emission value a	6 m/s (prototype)
Sound pressure (1m)	84 dB(A) (open environment) 94 dB(A) (closed environment)

**Table 1. Specifications for the electric rock drill.**

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### 3.2 Project planning

A formal development project plan was developed in the first quarter of 2000. Design and development of the prototype was planned to take about one year, and a product for testing and trials was due by the third quarter of 2001. The principal underground test venue was to be at Kopanang mine. Great Nologwa became involved with drill bit and thrust penetration testing at its surface site. TauTona and Moab Khotsong were to be the primary roll-out targets and as such were involved with the Kopanang trials.

Although the subject of this paper is the experience at TauTona, it is felt worthwhile to include the issues and steps included in the Kopanang trials. This will provide guidance for readers who are contemplating initiatives involving the introduction of new technologies. Also, it must be acknowledged that the successful implementation at TauTona was at least in part reliant on the quality of the groundwork performed at Kopanang.

#### 3.2.1 Preparation for trials

Following internal testing by Hilti, the first prototype was to be available on site at Kopanang by 1 July 2001. In preparation for this a number of matters required attention. These were:

- Selection and training of operational crew including the Section Manager, Mine Overseer, miner and drill crew.
- Introduction of the electric drill concept to the representative Union.
- Compilation of lesson plans and operational procedures.
- Selection of a suitable workplace.
- Upgrading and preparation of electrical reticulation – 500v & 220v.
- Upgrading and preparation of water reticulation – 3-5 Bar.
- Upgrading and preparation of compressed air reticulation.
- Upgrading of lighting system.
- Upgrading of ventilation system.
- Upgrading and preparation of support system.
- Provision of equipment including winches.
- Provision of rolling stock for rock and material transport including lockable material cars.
- upgrading communication system.
- upgrading of maintenance and storage area including a lockable store, adequate lighting, telephone communications, 220v power supply, and a bench vice. (Figure 4)



Figure 4. Underground store 2005 - TauTona

Other than to meet the requirements for monitoring, observation and data capture, the upgrading referred to above was only performed to satisfy the requirements of the new technology. In other words, the completed work would be the standard for future implementations. For meaningful conclusions to be drawn, the

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circumstances in a test site must be as close to a normal production environment as possible. In this case, a normal underground stope was used and the team was still expected to meet the monthly production target. As regards operating procedures, the only difference from operations with pneumatic drills was that to prevent theft, the electric drills were removed to a secure store before blasting.

### 3.2 Maintenance and logistics

In the areas of drill maintenance and logistics, the following matters had to be addressed:

- Performance of a maintenance issue-based risk assessment.
- Introduction of the maintenance and operational crews to maintenance schedules.
- Creation of a maintenance recording and control system.
- Creation of a breakdown recording and reporting system.
- Creation of a cost and availability recording and reporting system.
- Creation of an asset tracking system.

Where existing systems possess the capability to be expanded to incorporate the needs of a new technology, then it would be unnecessary to create an additional one. An example of this is the asset tracking requirement. Many mines already possess adequate systems for tracking such things as caplamps and gas testing devices etc.

### 3.3 Asset protection

Security matters to be addressed included equipment and unit identification, waybill control and service crew access control.

### 3.4 Data capture and recording requirements

For purposes of analysis, the data capture and recording process requirements can be extensive and usually involve the utilisation of experienced Industrial Engineers. If the data collection is not performed in a consistent and repeatable manner, any conclusions drawn will be reduced in value, and the cost of the data capture and analysis effort will be wasted. The need to capture representative data on current equipment and performances should also not be overlooked. In this case, data on the current performance of drill steel and on the current performance, as well as the cost of maintenance on pneumatic drills was captured. A cost capturing system was developed to enable a cost and performance comparison between the pneumatic drill and the Hilti electric drill to be performed.

### 3.5 Back-up equipment

Investment in the test environment should also not be underestimated. At Kopanang, by the end of July 2001 there were ten drills on site, with spares and basic equipment for sixty machines. Hilti field personnel were also on site and had completed their induction into mine procedures.

### 3.6 Test protocol and basis of evaluation

Two other vital parts of the process need to be developed. One is the test protocol. That is a scope document detailing how the testing will be performed, as well as what will, and what will not, be incorporated into the process. The other is the basis on which the evaluation will be made. In other words, what the criteria for success will be.

### 3.7 Consequences of successful testing

Elements which depend on the successful conclusion of trials are:

- Acquisition of a budget provision.
- Forecast for the roll-out.
- Compilation and administration of the contract with the supplier.

At this stage it was premature to attempt to complete these elements before the trials had been successfully concluded.

## 4 Summary of Kopanang trial results

### 4.1 Failure of the clip-off bit

Testing underground started on the 3<sup>rd</sup> of August 2001. Due to the stressed and crushed ground conditions, the clip on the bit failed after only a few holes thus rendering the system ineffective. Also, the overall performance of the clip-off bit was unexpectedly lower than the results which had been achieved with it by Hilti at their facility in Germany. An average penetration rate of about 4 min/m was being achieved at Kopanang. Although this is comparable to a pneumatic machine, it is not sufficient by itself to warrant a

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change of technology. Penetration rate is a function of ground conditions and the operator's skill in controlling the thrust leg. Due to the unexpected high failure rate of the clip, Hilti decided to continue the tests utilising knock-off bits. Their penetration performance was inferior to that of the clip-off bit. An average penetration rate of about 5 min/m was achieved. This was about 20% below that of the clip-off bit.

### 4.2 Drilling time and wear rates

Total drilling time is what affects the effectiveness of the stoping cycle, and so in addition to penetration rate achievements, the trials were also concerned with collaring time, drill stem extraction time, as well as ease of handling. Collaring time was used to measure the ease of handling of the machine. A low collaring time indicated an easily handled machine.

The average collaring time for the knock-off bit was 28% greater than for the clip-off bit; and the extraction time of the knock-off bit was 19% greater than for the clip-off bit. Despite these performances, given that the clip-off concept had been shown to be lacking in robustness for underground conditions in South Africa, Hilti decided to test different types of knock-off bits in order to try to replicate the penetration rates and collaring and extraction times that they knew would be necessary to make the electric drill a viable competitor for pneumatic technology. Several configurations were tested with no outstanding result. It was clear that further development was required to improve the connecting mechanism of the bit onto the drill stem. Prior to failure, clip-off bits had demonstrated unacceptably high wear rates, averaging 20m to failure against 70m typically achieved by a pneumatic button bit.

Redesign of the whole bit assembly became a high priority for Hilti.

### 4.3 Mechanical damage

Occasionally machines were damaged by being dropped or otherwise carelessly handled. The housing around the electronics seemed to be particularly vulnerable, and sometimes there was consequent internal damage. As it was occurring while the machines were in transit as part of the maintenance process, a protective mechanism was developed to prevent it. Material cars were modified to provide security as well as protection.

### 4.4 Improvements suggested by the production team

The underground production team was invited to attend a feedback function to identify problem areas which they thought could result in improvements. Their comments were as follows:

- Thrust leg is too long.
- Front handle is too big.
- Machine stalls when extracting steel, power inadequate.
- Thrust leg control valve is difficult to use and too big.
- Thrust leg grab is too small.
- Machine is not well balanced.
- Circular section drill steel is incapable of crushing small rocks and detritus in the hole behind the bit, making steel extraction difficult; suggested use of hexagonal section drill steel.
- Control valve works in the "wrong" direction.
- Delay on the switch needs to be removed.

As can be seen, these include some fundamental design issues and this after nearly five years of development on the machine.

Positive comments on the machine which the team noted were:

- It produced lower noise levels.
- Only one operator was required at Kopanang (note that the West Wits mines are among the last to retain two operators on pneumatic stope drilling machines).
- It was easy to handle.
- It provided a mist-free drilling environment.
- Connections and piping were easier to manipulate.
- The modular design simplified maintenance.
- It had less mass than a pneumatic drill.
- In-stope lighting became feasible.

So far it appeared that the ergonomic and environmental expectations of electric drilling were being met, but that the production requirements were not.

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**Figure 5. Illustration of differences in working environment**

### 5 Cost comparison

As part of the trial at Kopanang, a cost comparison was performed to determine any savings attributable to electric drilling of stope shotholes. Four areas of contributory costs were identified. However, for lack of reliable data, assumptions were made that the costs attributable to electric drilling would be the same as that for pneumatic drilling in the areas of consumables and maintenance. In practice, it was expected that savings would accrue from these elements, thus any conclusion reached would be conservative in nature.

The areas for analysis were thus:

- energy.
- compensation of drill operators for noise-induced hearing loss.

Energy consumption calculations were reduced to a basis of cost per drilled metre for ease of comparison. Based on observations made during the trials, the average time taken to drill a 1m hole was:

- for the Hilti electric drill: 5.11 minutes
- for a Seco S215 pneumatic drill: 3.38 minutes

#### 5.1 Energy costs

Based on the unit price and rated consumption of a pneumatic drill, the compressed air cost was calculated to be R1.60/m. This figure excluded losses due to leakages in the reticulation system. As most of the leakages and abuse of compressed air occur inside the stope, the actual energy cost for pneumatic drilling is higher than the calculated figure.

The cost of electric power was calculated at R0,02/m. The notional saving was thus R1.58/m, and the potential saving attributable to the alternative energy source was even greater.

#### 5.2 Consumables

Only drill steel and drill bits were included in this analysis. TauTona mine had been achieving 51 metres per drill bit and 197 metres per drill steel in its pneumatic drilling activities. The costs were calculated as:

- R0.59/m for drill steel.
- R0.98/m for bits.

The total of R1.57/m was applied to the analysis for the electric drill for lack of alternative reliable data.

#### 5.3 Maintenance costs

The maintenance cost for the electric rock drills was assumed to be the same as the actual cost incurred for pneumatic drills for the purposes of the exercise.

#### 5.4 Compensation

One of the most important areas of concern with respect to drilling underground is the possible loss of hearing due to high noise levels of the pneumatic rock drills. Since the noise level of the electric rock drill is

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significantly lower, possible savings could accrue from the reduction in the amount of compensation payments.

For the purpose of the exercise, only the noise level of the drills was taken into account. The exposure times were assumed to be the same. In practice, if the electric drill did not provide for a reduction in exposure it would be unlikely to be introduced. On this basis, the potential reduction in compensation payments was conservatively calculated at 50%, which represents an amount in excess of R681 000 pa.

### 5.5 Summary

The combined effect of these conservative assumptions was a potential reduction in drilling cost of R0.34/m. This was an adequate basis on which to expand the trial, and to expose the drill to a range of underground situations within AngloGold.

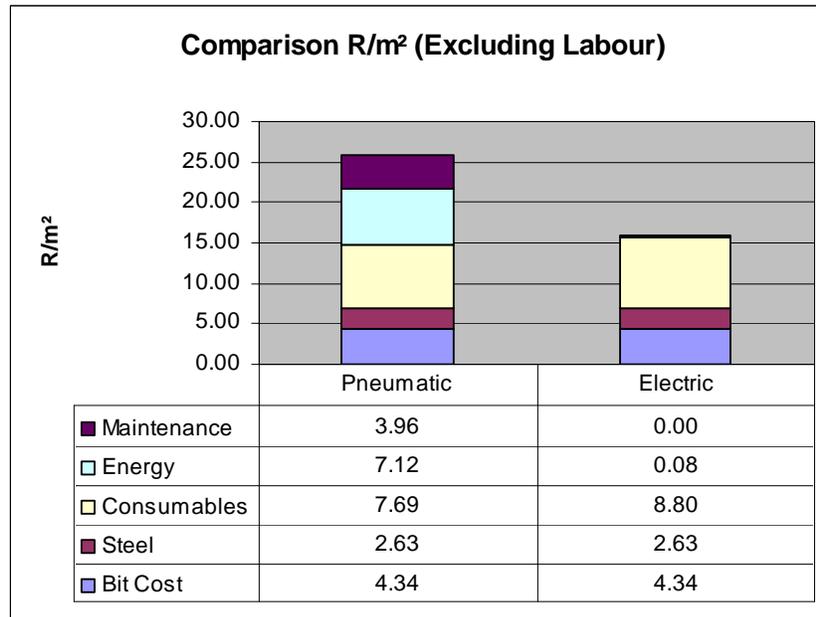


Figure 6. Cost comparison.

### 6 Design “freeze”

Held in October 2001, a design “freeze” meeting was to be the last opportunity to recommend any changes needed for the 2002 implementation. The outcomes took into account the comments from the production team, and were as follows:

- Front handle size would be reduced.
- Further development would take place on retracting power.
- Thrust leg design changes would be applied to:
  - o Bulk and mass reduction.
  - o Leg grab.
  - o Control valve:
    - Direction of operation.
    - Protrusion width to prevent fouling against support members.
    - Diameter.
    - Reduction of physical effort to operate.
    - Position next to the machine as required during single hand operation it would be very difficult to operate from the right hand side.
- Switch speed movement would be replaced by a magnetic on/off switch.
- Hexagonal section drill steel to be provided for.
- Stickers to be placed on the machine to indicate the need for the use of ear protection. (It was felt that due to the lower noise levels, employees might otherwise think that ear protection was unnecessary).

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Other requests which would have required redesign of the entire machine were rejected. Some of the problem areas are illustrated in figures: 7a, 7b and 8. Clearly, the thrust leg was the source of most of the problems. Only in the next generation of machines would increased motor power be introduced.



Figure 7a. Thrust leg control problems

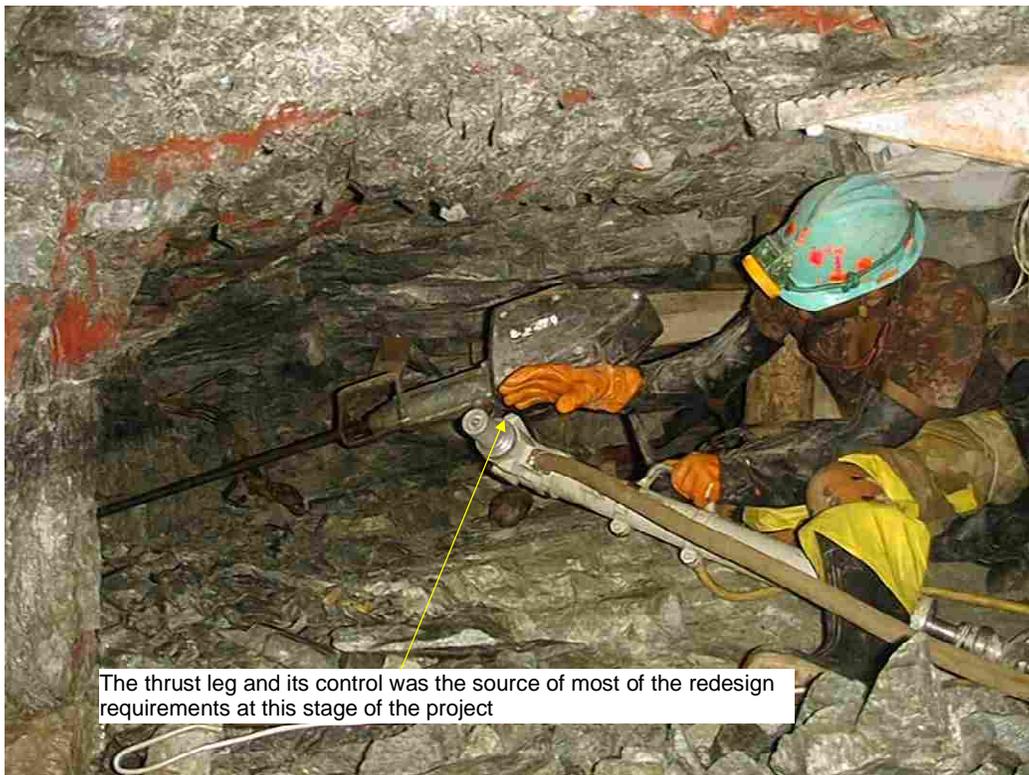
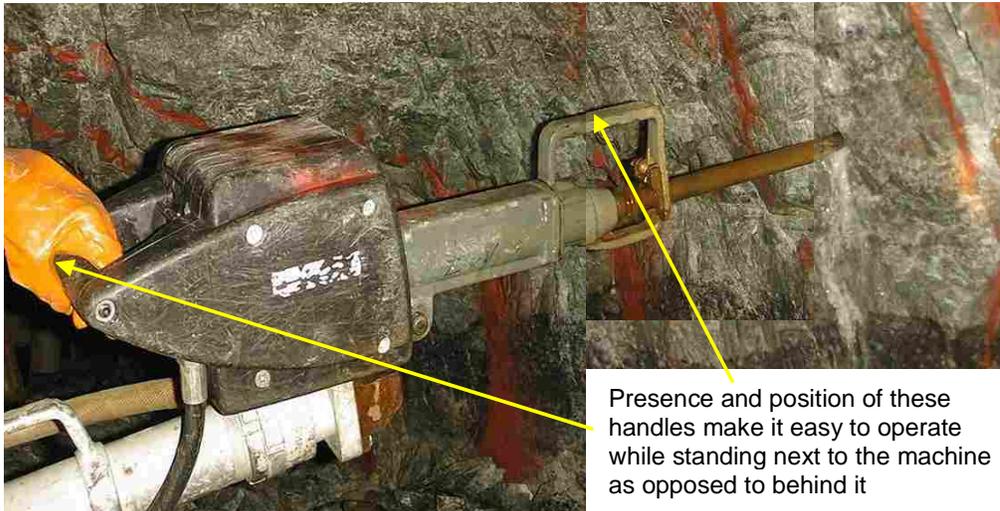


Figure 7b. Thrust leg control problems



**Figure 8. Machine handles**

### 7 TauTona trials

At this point it is worth restating the project aims and targets in numerical terms. The desired outcomes were developed from the earlier statements and requirements as being:

- Instantaneous penetration rate of less than 3min/m.
- Face advance of more than 12m/month.
- Labour productivity of more than 24m<sup>2</sup>/ISE.
- Nil lost blasts attributable to electric drills.

#### 7.1 Trial sites

Having established the feasibility of electric drilling in principle, more detailed planning for rigorous trials were prepared. It had originally been intended to run trials at three different mines. In addition to the Kopanang site, trials were to have been conducted at Moab Khotsonq and at TauTona. The trial at Moab Khotsonq was to have been in a development end application. In the event, it never really got started due to the lack of a suitable site, and the policy of simultaneous testing in more than one potential application area was discontinued shortly afterwards. In other words, it was decided that only when a technology had been found to be practicable in one application would its possible migration into other applications be considered. Early in 2003 the Kopanang site became unviable due to relatively poor Hilti penetration rates in comparison to the pneumatic Seco S215 drills. So by mid-2003, the only operating trial site left was at TauTona. At this time, every single mine was actively engaged in one or more cost-reduction initiatives. Kopanang was achieving significant success with its "Power team" concept, and perhaps not unnaturally was focussing most of its resources into that. On the other hand, TauTona suffered from a chronic problem of low compressed air pressure due to aging infrastructure and distances to the underground workings. To meet the production commitments, long shifts were being worked in the stopes as a result of length of time required to complete drilling of the faces. The electric drill potentially provided an immediate solution to this problem, and therefore there was very little resistance to its introduction, and willingness to participate in testing was easily obtained from the crews. Thus as far as TauTona was concerned, the acceptance issue solved itself.

#### 7.2 Issues to be addressed

In addition to the design improvements previously noted as being required on the drill itself, other cost and operational issues were receiving attention. Between March and July 2002, these were crystallised into the following topics.

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### 7.2.1 Cost issues

- The effect of a different penetration rate on shift duration needed to be studied.
- Robustness and wear resistance capability of trailing cables needed to be improved.
- Rationalisation of electrical reticulation for the drills was required; a manifold should serve four drills from one stope gully box.
- Accurate measurements of compressed air consumption by pneumatic machines were necessary for a proper cost comparison to be made with electric drills.
- Statistical data on the reliability of both types of drill needed to be accumulated.
- The total costs of the logistics of drilling needed to be determined.
- Data was required to make a comparison between the operating cost of air legs and water legs.
- The saving in the consumption of compressed air attributable to the use of a water leg needed to be determined.

### 7.2.2 Operational issues

- So-called "white knuckle" syndrome and any other effects of vibration needed to be studied. It was generally agreed at the time that Anglo Platinum would conduct these studies.
- Other possible applications for the electric drill, eg roof bolting in stopes needed to be determined.
- The skills required for maintenance and testing of the total electric drilling system needed to be established.
- The method of measuring the health and safety effects needed to be determined.
- A redesigned electrical supply manifold was needed to facilitate forward moves.
- Cable suspension mechanisms needed to be designed.
- The need for drill steel extraction tools needed to be established.
- Means of preventing the ingress of debris into plugs was required.

### 7.2.3 Technical issues

- Determination of the effect of rotation index on penetration rate and on bit life.
- Determination of optimum penetration rates.
- Determination of optimum thrust required for drilling with button bits on both pneumatic and electric drills.
- Determination of penetration rates of pneumatic drills at supply pressures between 200kPa and 380kPa (typical in-stope compressed air pressure at TauTona).
- Evaluation of Hilti bit types under controlled conditions.

TauTona also fulfilled the preparatory requirements detailed in Section 3.

### 7.2.4 The role of AngloGold Ashanti Mining Technologies (AMT)

The involvement by AMT in the project had steadily increased with more focus from the Industrial Engineering resources adding to the existing mechanical and electrical engineering experts assigned to it. Their experience in the testing and trials of other technological innovations made them an integral part of the development and monitoring of the Hilti drills, and in its ongoing management and control aspects. This left the line management at the mines generally, and at TauTona in particular, able to concentrate on the practical aspects. Responsibility for the test protocols; data capture methodologies, recording and analysis; research and calculations associated with the issues listed above was left in the hands of AMT.

At this stage a number of agreements were reached. They were that:

- The number of drills on trial would be increased to 48.
- A financial benefit study would be conducted utilising AMT's resources.
- Hilti would provide some purchasing scenarios.
- Logistics and infrastructure would be addressed by the project team.
- Local suppliers for drill steel and bits were to be established by Hilti.
- Testing activities should not negatively impact on production.

### 7.2.5 Roll-out scenarios

The potential for wider implementation of electric drill technology within AngloGold Ashanti mines had been assessed in terms a three scenarios, the smallest of which restricted itself to areas in which compressed air supply was low or non-existent. The other two were: one, to restrict the introduction of electric drills to new mines; and two, to replace pneumatic drills throughout the AngloGold Ashanti gold mines in South Africa wherever practicable. For the time being, roll-out was only considered for the compressed air pressure constrained applications, and the size of this segment and its associated training and establishment requirements was in any case assessed to be a significant undertaking. Commercial aspects which would

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arise for Hilti in the wider underground mining market from a successful development of the product were also discussed and agreements reached on them. Feedback and follow-up was scheduled for a workshop to be held in September 2002.

### 7.3 Situation as at mid-2002

To summarise the status and responsibilities as at mid-2002,

- Hilti were working on:
  - o Improving drill bit reliability and life.
  - o Thrust leg controls.
  - o Retraction power.
  - o Local sources for bits and drill steel.
  - o Purchasing scenarios.
- AMT were working on:
  - o Cost and operating parameter measurement and evaluation.
  - o Contract management.
  - o Assisting Hilti with technical evaluations.
- AngloGold Ashanti corporate engineering department were working on:
  - o Electrical reticulation.
- Kopanang and TauTona mines were:
  - o Performing trials.
  - o Reporting progress.

It is important to note that up to this point, few trial results had matched the penetration rate of pneumatic machines. However, compressed air pressures underground can vary widely. Therefore, because an electric drill could perform at the same rate regardless of its location in relation to the energy source, it was felt that the potential for productivity improvement was a realistic expectation. The following graphs illustrate the results achieved.

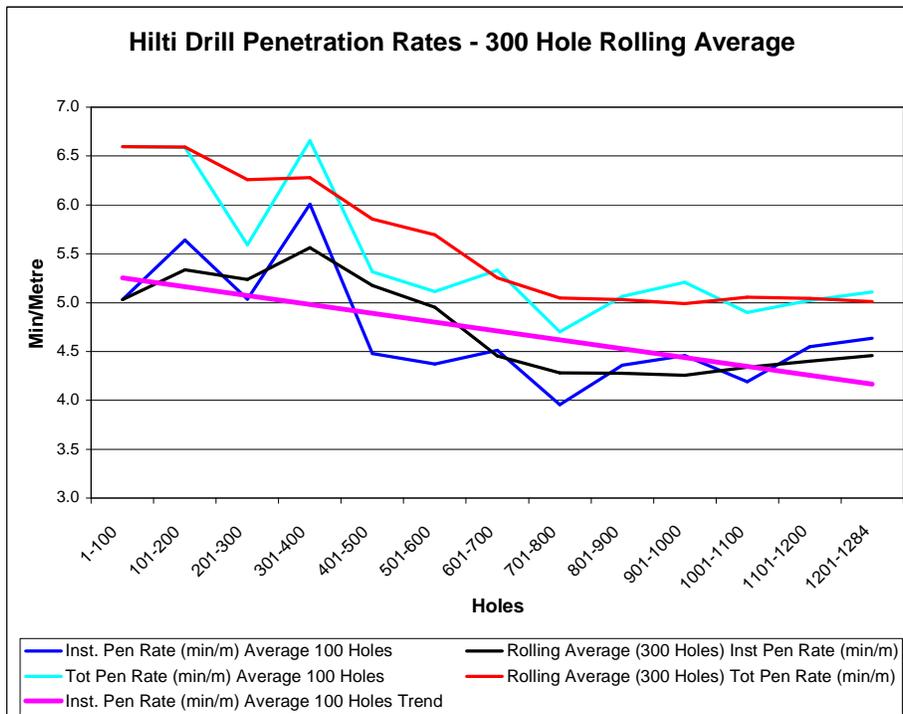


Figure 9. Penetration rate performances

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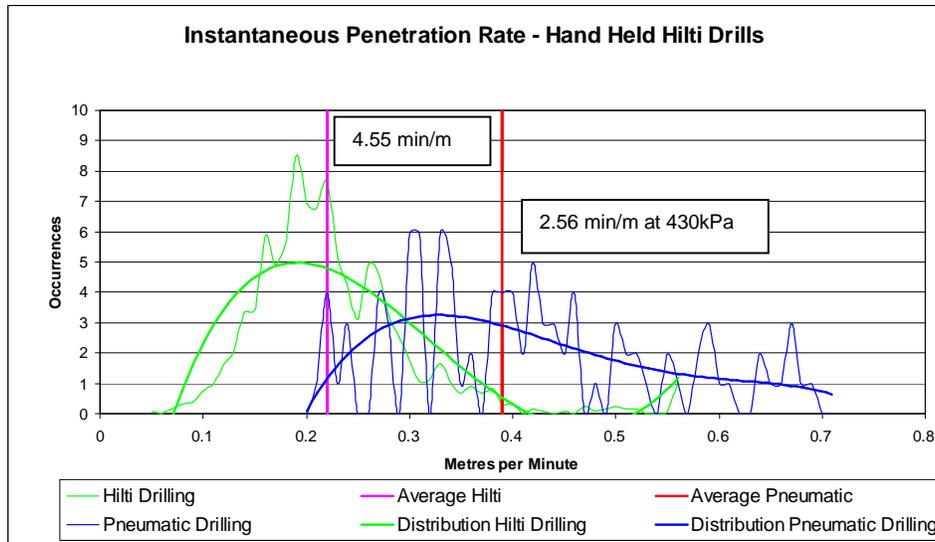


Figure 10. Comparative instantaneous penetration rates

### 7.4 Problems encountered during the third quarter of 2002

Weekly reports were produced from the third quarter of 2002 in which in addition to a diary of activities, detailed statistics on the number of drills in operation, number of holes drilled, environmental conditions encountered, bit types used and durations of each element of the drilling process were recorded. The targeted performance of 3.5 min/metre remained elusive. Some of the hurdles which seemed to prevent its achievement were recorded as:

- Drill problems:
  - o Shank breakage
  - o Hilti plug damage
- Bit problems:
  - o Buttons failing on bits
- Infrastructure problems:
  - o Water supply interruption
  - o Cable damage
  - o Electrical supply failure

In other words, a lot of the normal production problems affected progress of the trials. By October 2002, a decision was made to pursue bit development off-site. The best performing of Hilti's knock-off types was kept on the trial drills while this took place. Hilti was still keen to try to reintroduce the clip-off design which had provided such good penetration in their factory tests, and it was clear that this was becoming a key issue. Performances remained in 4.5 to 5 min/m range. The detailed observations were also showing that a significant difference existed between the penetration rate of top holes and bottom holes, the former taking 30% more time to drill. This was due to relative rock hardness above and below the reef contact, however, with the progressive improvement in overall penetration rates later in the project, it ceased to be an issue.

In December 2002, perhaps as a result of accumulated experience by the drillers, average penetration rates fell below 4min/m for the first time. A left-hand rotation drill was introduced in January 2003 to facilitate the drilling of roofbolts; this machine also had heavier striking pistons. To address the bit failures, larger flushing ports were introduced. The experienced crew achieved an average penetration rate of 3.76 min/m, however an inexperienced one was only able to achieve 4.45 min/m with this version. It is perhaps worth repeating that this was still an improvement over the normal situation at TauTona with its low compressed air pressure problem. Seismic events resulted firstly in the need to relocate the TauTona test site, and later interrupted tests for several days. The penetration rates achieved on re-entering the test site were excellent, but the fact that the face advance exceeded the steel length indicated that that the face had been crushed by the seismic event, and these results were not purely representative of drill performance and this data was disregarded from the statistical database. Drill bit life was still well below that for pneumatic equivalents.

### 7.5 Progress made during 2003

A formal basis for comparison with pneumatic equipment was established in February 2003 in terms of which 500 samples would be taken. This was completed in April and resulted in the determination of an average penetration rate of 4,5min/m and a breakeven bit life of 40m of drilling. At this time, a decision was taken to

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equip drills with trailing cables to the same specification for abrasion resistance as applied in the collieries. This required a modification to the plugs. A second decision was taken, which demonstrated confidence in the progress of the work. This was to implement a six panel trial in the 116/57 raise beginning in February at TauTona.

SIMRAC tests on the noise and vibration of the electric drill were completed in February 2003, and in both areas, it outperformed the Seco S215. As there were likely to be some cost savings associated with these issues, especially as far as the medical and protective equipment aspects were concerned, it was decided that they should be quantified. The work would however be dependant on the accumulation of representative data, and therefore became a matter for AMT to include in their observations and analysis.

A dedicated store and workshop was completed by May of 2003 and this enhanced the repair and maintenance function. In the same month, an average penetration rate of 3,93minutes/m was achieved, with a bit of life nearly 30m. Cable failures, gland failures and electronic housing failures continued to bedevil the project. Hilti established that the housing had been incorrectly cast, but resolution of the other problems was not so simple.

Automation of the stock control system was begun in June 2003.



Figure 11. Completed underground store

Penetration rates reverted to more than 4min/m in July and August, so the requirement for a more powerful motor was confirmed. The 1,8kW version was replaced by a 2,2kW model in October.

	Instantaneous penetration rate (min/m)	Average penetration rate(min/m)
Pneumatic S 215	3,99	4,25
Hilti original	5,17	5,79
Hilti heavier piston	4,24	5,09
Hilti 2,2kW expected performance	2,98	3,47
Hilti 2,2kW actual	3,85	4,43

Table 2. Representative penetration rate data

In the meantime, problems of chuck failures and leaking seals were the main difficulties being experienced.

### 7.5.1 Establishment of a User Group

A User Group had been constituted and regular meetings were convened to enable the interchange of experience outside the formal project management reporting structure. This mechanism provided a means of faster problem identification and multiple alternative solution suggestions in the manner of a “think tank”. On the basis of the User Group’s inputs, it was possible to redirect the progress of design changes sooner rather than later. By this means, the effectiveness in the use of R&D funds must have been improved, although by how much is impossible to calculate.

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### 7.6 Achievements as at the end of 2003

The reader may be interested to compare a number of parameters as at the end of 2003; that is about halfway through the eventual development period.

	Pneumatic (S215)	Hilti (2.2kW version)
Mass net of thrust leg (kg)	21.5	22.6
Mass including thrust leg and lubricator (kg)	39.75	33.05
In-stope noise level (dB(A))	113	93
Rockdrill (m/failure)	800	128
Thrust leg (m/failure)	1500	667
Drill bits (m/failure)	40	27
Drill bits (R/m <sup>2</sup> )	3.98	8.37*
Drill steel (R/m <sup>2</sup> )	7.15	6.88*
Energy cost (R/m <sup>2</sup> )	8.52	0.10
Air conduit cost (R/m <sup>2</sup> )	4.82	Not applicable
Electric cable cost (R/m <sup>2</sup> )	Not applicable	101.62
Total cost (R/m <sup>2</sup> )	31.62	175.02
Bank-to-bank shift time (min)	565	593

\* as per contract and affected by unfavourable movement of the conversion rate between the South African Rand and the Swiss Franc.

**Table 3. Interim comparative data**

Hilti performances do not look too promising from this set of data. However, no lost blasts had occurred due to Hilti drills during the period of the study. Also, an upgraded drill was had been released; the 2,2kW version. As for the other problems, there were none for which some sort of solution was not being developed. The question was whether solutions would be found in time and at a cost which would retain the viability of the project.

## 8 Progress during 2004

The future of the project came under scrutiny during the first quarter of 2004, and at a meeting in March 2004, the question of closing the project had been discussed. At issue was the cost involved, the length of time that the project had been in progress and the uncontrollable effects of the exchange rate to the Swiss Franc, the currency in which the contract had been framed. It was agreed to continue with the project, however under a more streamlined management structure which gave greater responsibility to the direct supervision, and diluted the corporate office involvement. In this way, decision-making and responses would take place more quickly. It also took into account the wider concern for the long-term need to improve productivity and the probable concomitant cost reductions arising from the use of electric drills.

Design issues which were still unresolved as at March 2004 were:

- Stinger slippage.
- Flushing system constraints.
- Drill bit life.

Throughout 2004, trials continued on the expanded number of panels and the database became more representative of the range of conditions under which analysis could meaningfully be performed. Penetration rates achieved by 2,2kW drills were consistently better than the pneumatic performance from April onwards. Cost performance showed a progressive improvement due to the elimination of failures of the equipment, and probably to the increase in experience of use by the crews. By October production volume, labour productivity and face advance achievements were all better than target. As far as reliability issues were concerned the improvement is depicted in the following table.

## Electric Rock Drilling at TauTona Mine

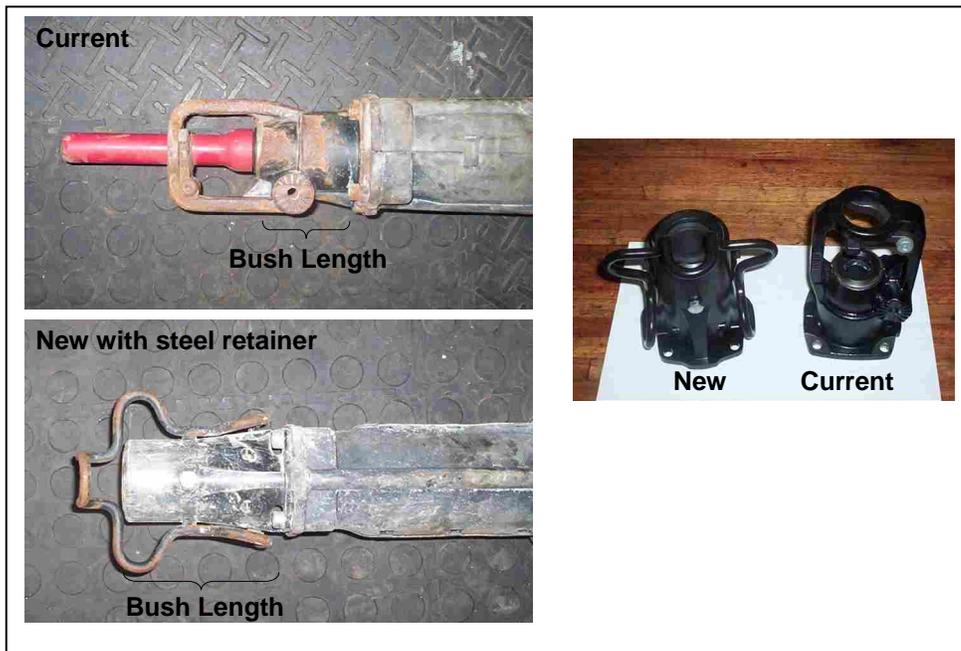
	End 2003 for the 1,8kW drill	Apr-Oct 2004 for the 2,2kW drill
m/bit	27	25
m drilled per drill failure	128	111
m drilled per thrust leg failure	667	2090

**Table 4. Comparative reliability statistics to October 2004**

Direct cost performance excluding labour was about 5% worse than target, however, the project objective allowed for a cost premium of 10% above the breakeven unit cost for pneumatic drills.

### 9 Achievements from the end of 2004 to date

Perseverance and application, and those attributes described in the introduction began to bring returns from the end of 2004. The various activities around the redesign work produced improvements in performance, reliability and thereby reductions in unit cost. At the end of the year, a new hammering mechanism (NHM) had been introduced (figures 12a and b). It involved a reduction in the impact area to achieve more efficient energy transfer into the drill steel, with a more robust and longer bush. The latter was developed to counter the wear which was being experienced on the existing bush which in turn permitted water to be forced back into the drill. This coupled with a redesign of the chuck, the use of hexagonal drill steel and a new bit had resulted by mid 2005 in reliable and adequate rates of penetration. Hilti had needed to be convinced about the need for hexagonal section drill steel, otherwise the change might have occurred sooner. They still maintained hope that the clip-off bit can be developed for underground applications. Thus after twelve years, a machine had been developed which provided acceptable performance and was robust enough.



**Figure 12a. New hammering mechanism**



**Figure 12b. New hammering mechanism**

Table 4 is extended by an additional column to illustrate the progressive improvement in table 5. Illustrations of the NHM are provided below. The new hammering mechanism achieved an instantaneous penetration rate of 2,92min/m and an overall rate of 3.44 min/m. Labour productivity was up to 22,7m<sup>2</sup>/isw and monthly face advance was 10,1m. (For reference, the applicable targets were 3min/m penetration; 24m<sup>2</sup>/isw and 12m/month face advance. The trends on the efficiency and face advance parameters were both rising). The positive impact on the shift length was further enhanced by the ability to reduce the complement of drillers by one person and still remain within the desired time limit.

	<b>Initial Trial 1.8kW</b>	<b>Current 2.2kW</b>
<b>m<sup>2</sup> Broken</b>	<b>12 930</b>	<b>502 627</b>
<b>Metres drilled / bit</b>	<b>21.4</b>	<b>30.3</b>
<b>Metres drilled / steel</b>	<b>112.7</b>	<b>105.1</b>
<b>Metres drilled / drill failure / service</b>	<b>48.2</b>	<b>313.0</b>
<b>Metres drilled / water leg failure</b>	<b>1 866</b>	<b>2 216</b>
<b>Metres drilled / cable failure</b>	<b>422</b>	<b>3 766</b>

**Table 5. Comparative reliability statistics**

Electrical reticulation had similarly been improved. Not only had the abrasion-resistant cables contributed to this, but a system of supply manifolds independent of the winch power supply had simplified the reticulation.

## Electric Rock Drilling at TauTona Mine



**Figure 13. Current electrical reticulation - TauTona**

Through the development of an adapter, hexagonal section drill steel had been successfully introduced, with a marked improvement in retraction.



**Figure 14. Adapter for hexagonal drill steel**

As a cost-reduction measure, a locally manufactured bit was developed.

By November 2005 cost exclusive of labour had fallen from R40/m<sup>2</sup> to R31/m<sup>2</sup>. Rollout to a population of 90 drills was planned for completion by the end of the first quarter of 2006.

In February 2006 TauTona Mine was given the go ahead by corporate office to roll out the Hilti drills to all long term panels on the shaft and by the end of 2007 a total tool population of 236 drills was rolled out to 61 panels.

Expenditure by AngloGold Ashanti on direct project-related expenses exceeded R2 million in development capital.

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The capital cost of rolling out the Hilti drills to TauTona and the monthly operating costs have been summarised in table 6.

<b>Electrical Reticulation System</b>	
Gully rigs and cables per panel	R 40 000
Hilti plugs and cables per panel	R 27 817
Rollout cost per panel	R 67 817
Number of panels rolled out	61
Total Rollout Cost	R 4 136 813
<b>Monthly Operating Costs</b>	
Lease cost per drill	R 3 130
Drill population at TauTona	236
Total lease cost per month	R 738 694
Consumable cost per month	R 288 101
Total running cost per month	R 1 026 795

**Table 6. Rollout and monthly operating costs**

### 10 Summary

Twelve years ago, a vision of a better working environment in the stopes had been expressed. It had included references to productivity and cost-effectiveness. During the process of trial and evaluation of the electric drilling technology, these ideals were refined and in the final analysis for TauTona, the following has been successfully achieved:

- for safety; a reduction in injuries from environmental and noise-related hazards
- for productivity; an increase through a reduction in lost blasts due to poor air pressure
- for face advance; an increase of 1m per panel per month
- for costs; a reduction of 1 driller per panel to reduce direct drilling costs to the equivalent of pneumatic drilling

In terms of technical achievements, the NHM electric drill performs better than SECO S215 drills at TauTona Mine. The technology has been well accepted by drilling crews with little "resistance to change". No lost blasts have been directly attributed to electric drills.

Lessons that have been learnt during the rollout process have been:

- Have a realistic rollout schedule.
- Have dedicated crews for infrastructure installation, so as not to interfere with production.
- There needs to be good discipline in returning consumables, otherwise penalty clauses in the contract can be costly.
- Cable suspension is critical and needs to be kept away from scraper paths. Loss of one cable has a financial implication of R6 000 per cable.
- In-stope drill transport & storage is critical. The Hilti drills are not as robust as the Seco S215 drills and any non typical damage is charged to the mine for repairs.
- Buy-in from line supervision is of utmost importance. While the drill is well accepted by the drilling crews, line supervision can hamper implementation.

## Electric Rock Drilling at TauTona Mine



### Acknowledgements

The material and records which have accumulated on this project are voluminous. The number of individuals who have been involved with it is numerous. A special word of thanks to Steve Ebben, Senior Industrial Engineer for his assistance in the preparation of this paper. TauTona is the beneficiary of all these efforts, without which these achievements would not have been possible.

### Development and implementation of an electrically-powered stope rockdrill for TauTona Mine

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