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Electric rock drilling system for in-stope mining in platinum operations

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The strategic mission of the South African mining industry is to extract the mineral assets in an energy efficient, economical and safe manner. Drilling has received particular attention in the last few years. As the operations move away from the power source, conventional and old drilling technology result in poor penetration rates, increased drilling shift lengths, slow face advances and limited stope efficiencies. The need for an alternate mining method, performed by a skilled workforce, to increase productivity, has led to the development of the electric rock drilling system for in-stope mining operations.

The focus of this paper is a systematic evaluation of the electric rock drilling system as a function of production and technical parameters, in the platinum orebody. The particular electrical reticulation system is illustrated. Power usage, problems experienced, and solutions are described. The safe use of the recently developed drill is elaborated upon by describing protection devices. The testing and certification process, for approval by the recognized authorities, are documented.

The human factor is also considered. Known detrimental factors of high noise exposure, vibrations levels and oil emissions are reviewed.

In conclusion, recommendations on future strategies for the implementation of electric drilling technology within the mining and construction industries, is included.

Introduction

The mining industry is an intense user of energy and services. In South Africa, the opportunity exists to develop energy efficient, cost-effective and safe methods of extracting the wealth of minerals available.

The likelihood is to shift towards full electric mining[9]. At the centre of production, conventional rock drilling methods are being challenged in favour of energy efficient alternatives. Problems with the supply and condition of compressed air reticulation systems indicate excessive air losses, due to leaking air columns and poor maintenance. Furthermore, frictional losses suffered in pipe network systems increase, as more remote stopes are brought into production.

Initially, operational results with electric drills were initially poor and inconsistent, compared to pneumatic operation. However, with continuous monitoring and realization of equipment improvement, electric drilling is gaining recognition as an energy efficient and suitable method of mining.

Scope of study

The study concentrates on comparing the current production performance of the electric rock drill, in the same platinum reef band, namely Upper Group 2 (UG2), to previously accumulated data of parameters measured on trial and production stopes. Technical dynamics are measured with operational data, collected monthly, with diagnostic equipment[3].

These high-level parameters and other considerations are displayed in Figure 1, and are evaluated chronologically over a period of twelve months, for expansion/replacement operations.

Evaluation of the electric rock drill

The study of key performance parameters, to successfully implement the use of electric rock drills for full in-stope production, is ongoing. In this paper, results from Amandelbult, Brakspruit and Hackney shafts are reviewed. Continued tests are being conducted to optimize drilling, minimize maintenance and reduce capital outlay.

Production measurements (KPIs)

The production efficiency of the electric rock drill is measured through common key performance indicators (KPIs). These are the drilling cycle times and drill penetration rate. However, fair assessment of these factors is only achieved by taking into account the platinum mining environment. Apart from the multifaceted geology of the platinum reefs, the mining environment is altered by quasi-static and dynamic loading conditions.

Rock drillability and drilling cycle time

The mechanics of the rock breaking process are a combination of bit indentation, rock chip formation, chipping frequency and secondary crushing of chips[12]. The rock drillability is defined as the resistance of the drill bit to net penetration of the rock. It is a function of mineral composition, rock hardness, abrasiveness, porosity and crack growth intensity. These characteristics are commonly measured by the uniaxial compressive strength (UCS), the drilling rate index (DRI) and rock abrasivity.

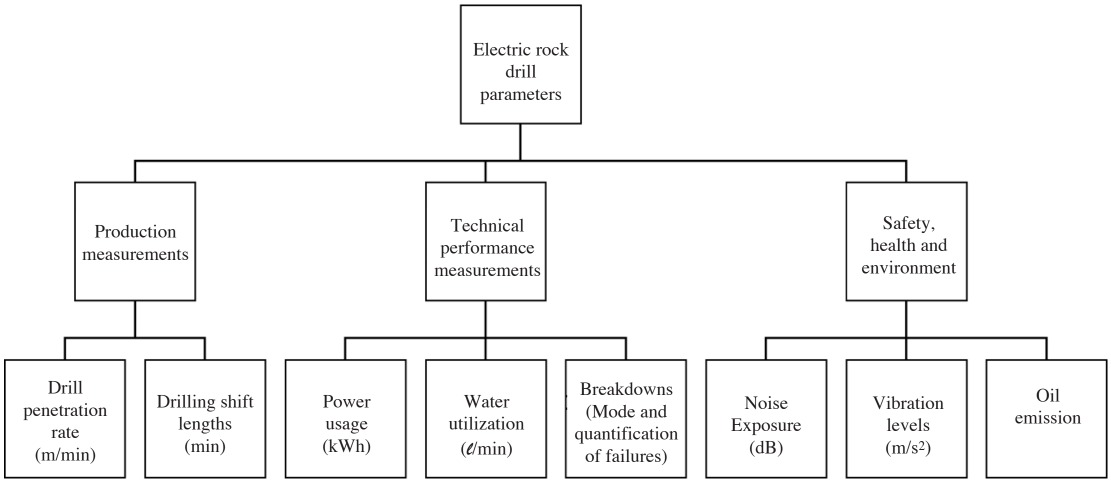

Figure 1. High-level production and technical parameters for electric rock drill evaluation

Both platinum-bearing reefs, namely Merensky (MR) and UG2, are a pegmatoidal (coarse-grained) feldspathic pyroxenite. The UCS of MR remains predominantly at 70 MPa. The UG2 reef, with a higher chromitite content, is higher in strength, and the UCS varies between 110 and 120 MPa. However, the low rock mass ratings (RMR) currently encountered in both reef types, require high drilling torques. Drillability is affected because of the lack of grip on rock fragments, resulting in low output torque, and the button bit wedging within the drilled hole.

The DRI provides a relative measurement of the penetration rate. The classification for norite and anorthosite are extremely low to low (values 20 to 50), and chromitite is ranked high to extremely high (values 70 to 125)[12]. Other factors that affect penetration rate are flushing of debris, blunt button bits and shank length, resulting from collar drift on old drill steels[13].

The rock abrasivity is determined by the bit wear index (BWI). It is dependent on the abrasive resistance of the button-bit material, the speed of the drill and the feed force. The abrasivity value (AV) is determined with the Vickers test yielding the Vickers hardness number rock (VHNR). The VHRN values for norite and anorthosite are between 575 and 800, and chromitite has values 400 to 610[12]. MR is a harder rock than UG2, substantiating higher abrasion in MR.

At Amandelbult, the UG2 reef in the trial stope appears to feature a high degree of iron replacement, which increases rock hardness. Initially, this negatively affected drilling speeds[2].

Timing of the steps in the drilling process, from initiation and collaring to the auxiliary time to the adjacent hole, was gathered from the three UG2 operations, with drills rated at 2.2 kW and 250 rpm, but with six- or eight-button knock off bits, and 22 mm hexagonal drill steel stems. The drill stem length was 1.05 m at Brakspruit and Hackney shafts, and 1.2 m at Amandelbult shaft.

Results revealed that the drilling cycle is affected by the required length of the hole, penetration rate and the experience of the RDO. Varying the contact pressure/feed force into the rock material can affect the penetration rate in a linear relationship, irrespective of the energy provided to the drill steel[4].

A comparison to demonstrate average drilling times at the various platinum operations, using electric rock drills, revealed that a trend cannot yet be established. Lapses in record keeping and some inconsistent responses on monthly data sheets resulted in incomplete information. Operations were also affected by heterogeneous geology, shifting mine plans and the varying skill of the rock drill operator (RDO), thus reducing the amount of usable data. However, certain distinctive aspects were noticed.

Slow times were observed during the retraction of the water leg at Hackney shaft[14]. Consequently, the design was modified to reposition the centreline of the water leg closer to the gravitational centre of the drill housing.

Additionally, when the machine was stopped, there was an automatic shut-down of the water feed, rendering retraction difficult. This is under investigation[15], but currently, the RDO continues drilling during extraction of the drill from the hole.

The average cycle times have also improved since the motor speed has been modified to ramp-up from start to full speed. A slow-start has been introduced with a variable switch, increasing the percentage of the motor speed from 35% to 100% in eight (8) seconds. Instantaneous full speed resulted in overthrust of the drill, drawing maximum current, and hence stalling the drill.

A comparison of the progress made in drilling cycle times, with the practical data obtained from the stopes at the various operations, is shown in Figure 2. The cycle time is measured from initiation and collaring of one hole to the initiation of the adjacent hole. Alignment time is included. In each case, the water pressure was 500 kPa.

Although additional data are required to create a trend, it is noted that the average drilling times at all the operations have decreased in 2006. This decline is most obvious at Amandelbult shaft. Even though the hole lengths drilled are longer than at Brakspruit and Hackney shafts, the cycle time is the lowest by June 2006. No information was received as to whether the results were influenced by changed rock hardness, as a result of decreased iron replacement content.

Penetration rate

The penetration rate presents an approach to compare individual operations as a function of distance drilled and time, over a designated operation duration.

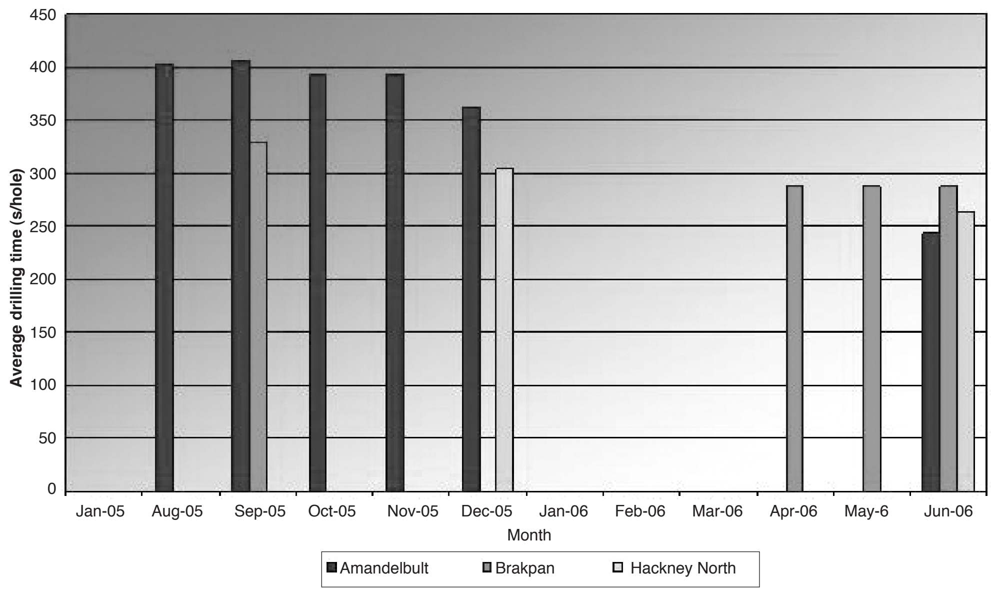

Figure 2. Average drilling cycle time in UG2 reef

- Since mid-year 2005, the drilling speeds at Amandelbult have reduced from a maximum of ten minutes to an average of less than five minutes for an effective hole length of ±1.2 m[7]
- Brakspruit shaft achieved an average of 5 minutes 24 seconds to drill 1.15 m in MR in September 2005, and in June 2006 it took 4 minutes and 30 seconds to drill 0.9 m in UG2 reef
- At the Hackney shaft, the best performance was obtained, namely 2 min and 36 sec to drill a 0.9 m effective hole length[7] in UG2 reef!

In general, penetration rates have reduced over twelve months, by an average 30% for a hole.

Currently, Amandelbult, Brakspruit and Hackney shafts are all mining UG2. No mining data are available for MR, and hence, slower penetration rates in MR cannot be proven. However, since the DRI and penetration rate are somewhat directly proportional, poorer drilling speeds in MR are anticipated.

Technical performance measurements

Power usage

The electric rock drill is powered by 240 Volts, 50 Hz, 1- or 3-phased motor, drawing a maximum current of 16 Amps. The rated power of the equipment differs for the application of the machine. Drilling in softer rock, such as coal and platinum, employ 250 rpm machines, while in hard-rock, as is the case with gold, mostly 205 rpm machines are utilized.

A reliable electrical system was designed and implemented to supply power to the drills. Two electrical supply systems are currently installed on Anglo Platinum, namely the single-phase and three-phase systems. The choice is dependent on the mining philosophy, flexibility of the operation, quality of power supply, and space and distance constraints[8].

The complete installation of the single-phase system used at Brakspruit and Twickenham mines, is located in the stope, requiring only one power supply system per panel. The primary power is obtained from the existing 550 V stope reticulation (e.g. from the face winch power supply or an appropriate gully box), and fed from a 550 V/220 V single-phase transformer (15 to 25 kVA, depending on the amount of 2.2 kW drills). In turn, this supplies a specially designed four- or five-socket ‘plug-in-face’ manifold box through 4-core power and control cables.

Voltage drop problems at the Brakspruit shaft were addressed by modifying the 220 V transformers[1], with minimum additional cabling required. A voltage drop greater than 5% warranted a transformer with multiple primary winding taps. A maximum of two,-thirty metre long trailing 4-core cables, in series, connecting the drill to the manifold box should be permitted. The voltage drop and potential for cable damage increases with additional cabling extensions.

The three-phase system used at Amandelbult was designed to cater for voltage fluctuations/current overload, that sometimes tripped the electric drills[11]. Figure 3 shows the single line diagrams (SLD) for the three-phase power reticulation.

The system is a dedicated power supply to the twelve drills or more, in addition to the 550 V stope supply. Also, it is designed to provide power for up to six drills per panel. A 50, 75 or 100 kVA transformer (550 V/400 V) is installed in the cross-cut, and fed from the nearest 630 kVA sub-station by a dedicated seven-core cable. This transformer feeds a four-way gully rig (one-incomer and three-outgoing gully boxes) in the stope.

The gully boxes supply power to three separate six-socket ‘plug-in-face’ manifold boxes (one per panel), where the phases are split to supply 220 V to the drills. Thus, one such system can supply power up to thirty electric drills[8]. This dedicated system requires a significant amount of additional cabling to the stope, but it has been successful in alleviating voltage drops.

The earthing system is effective throughout the power reticulation system. Firstly, earth continuity occurs from the transformer to the manifold, with the earth-wire in the four-core cable, in the single- and three-phase systems. Secondly, a pilot control wire circuit ensures continuity and earth proofing between the manifold box and the electric drill machine. The earth leakage unit provides protection through an armoured cable with a minimum sensitivity of 30 mA.

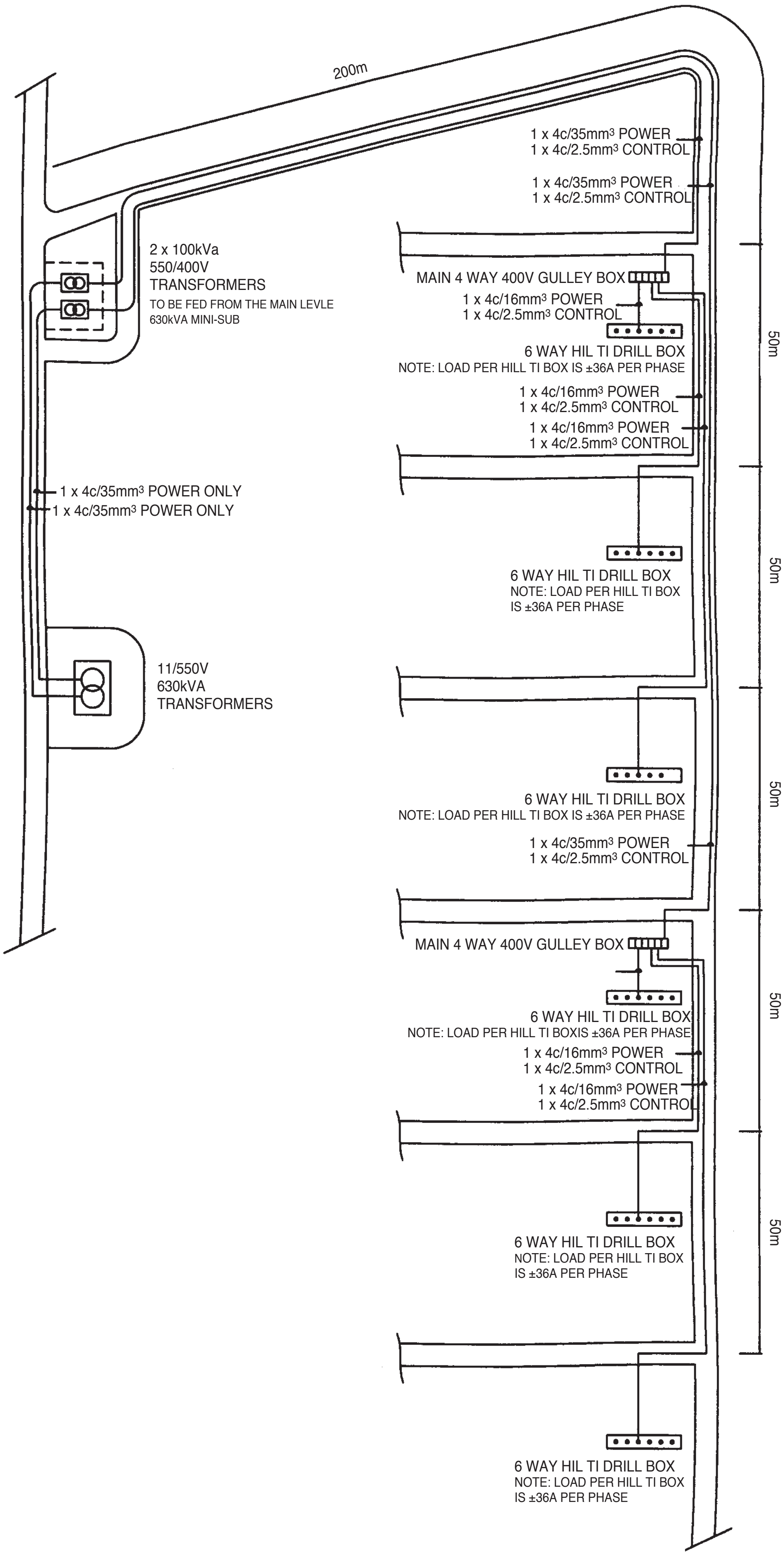

Figure 3. Single line diagram (SLD): layout of three-phase reticulation[8]

Water utilization

The electric rock drill utilizes mine service water (MSW), at a rate of six litres per minute, feeding into a rubberized water leg hose. A fixed ratio pressure reducing valve (PRV), designed at 2100 kPa, reduces pressure to 500 kPa, before entering the telescopic jackleg. A washer is slotted after the PRV, and ruptures, if the water feed pressure surpasses the pressure limit.

The water-driven jackleg has a control unit that acts as a pressure regulator to adjust the thrust, thus facilitating collaring and retraction. Retraction draws MSW at 24 ℓ/min.

Breakdown (modes and quantification of failures)

Information, gathered from breakdowns and repairs of the electric drill, provides detailed and mine statistics. The objective of the collected data is to improve and optimize the usage of the drill for certain mining conditions. The correct choice of drill heads and rods, thrust leg, electrical plugs and manifold boxes, and other consumables[15] reduce/eliminate downtime. As expected, the majority of failures were due to drill bit and steel. Cabling damage is also high.

A substantial number of other breakdowns are due to poor equipment transportation and handling practices from storage facilities to stoping areas. This has led to damaged or broken drill casings and internal components that are beyond the impact resistance of any rock drills. Blast damage justifies other types of non-specific damage. The immediate availability of a replacement drill ensures that the RDO productivity is not reduced. Figure 4 specifies which components fail and the frequency of failure.

Failures are prevented by regular schedules services. The requirement is built into the diagnostic management system of the drill. The mechanism timing the duration of the drilling operation is connected to a set of light emitting diodes (LED). These red and green light indicators provide a visual reminder when to send the electric drill to the workshop. A three hour forewarning time is programmed in the drill, to notify the RDO of a scheduled service. The time span between service intervals has increased from sixty hours to eighty hours, with equipment improvement and better treatment of the drills.

Drill consumables

The direction and application of the thrust force and rock breaking mechanisms/abrasivity are the two contributing factors to the wear rate and fatigue life of the drilling elements. In the first instance, inadequately varying the contact pressure/feed force into the rock affects the deterioration of components. Secondly, the rotary-percussive action of the drill is inhibited in softer rock, such as chromitite. The enumeration of these actions is the bit wear index (BWI). This quantifies the lifespan of the drill bit by combining the DRI and AV. Typical BWI value for anorthosite is 28, while for chromitite it is above 63[5].

Continued research has provided solutions to increase the lifespan of drilling elements. The new generation of knock-off button bits has carbide inserts at the base to prevent longitudinal cracking. The number of buttons has been increased from six to eight smaller units. This has augmented the average number of holes drilled per bit from 100 to 250. The screw-in drill steel has a cold forged rammer to strengthen the shaft from non-axial thrust forces. Additionally, the spline has been modified to better control the percussive drilling action[10].

Inside the housing, the connecting rod that drives the piston has been manufactured with increased width. This component is fabricated from durable plastic to ensure that it will be the only item to break in the event of failure. A vacuum exists between the metallic hammer and strike piston to avoid contact. A breather hole sucks in and pushes out air as the drive action occurs. The rammer absorbs shock through a rubberized inner section. Other internal components have been molded with resin for durability.

At each service, various items are replaced to decrease potential preventable breakdowns. The contents of a service pack comprise a connecting rod, seals, O-rings and bushes.

The water-driven jackleg of the electric drill is designed to be less sensitive to variations in pressure feed. The centreline was also repositioned with respect to the drill casing. The pressure is also regulated by the PRV, and the safety washer eliminates vast fluctuations in water supply rates.

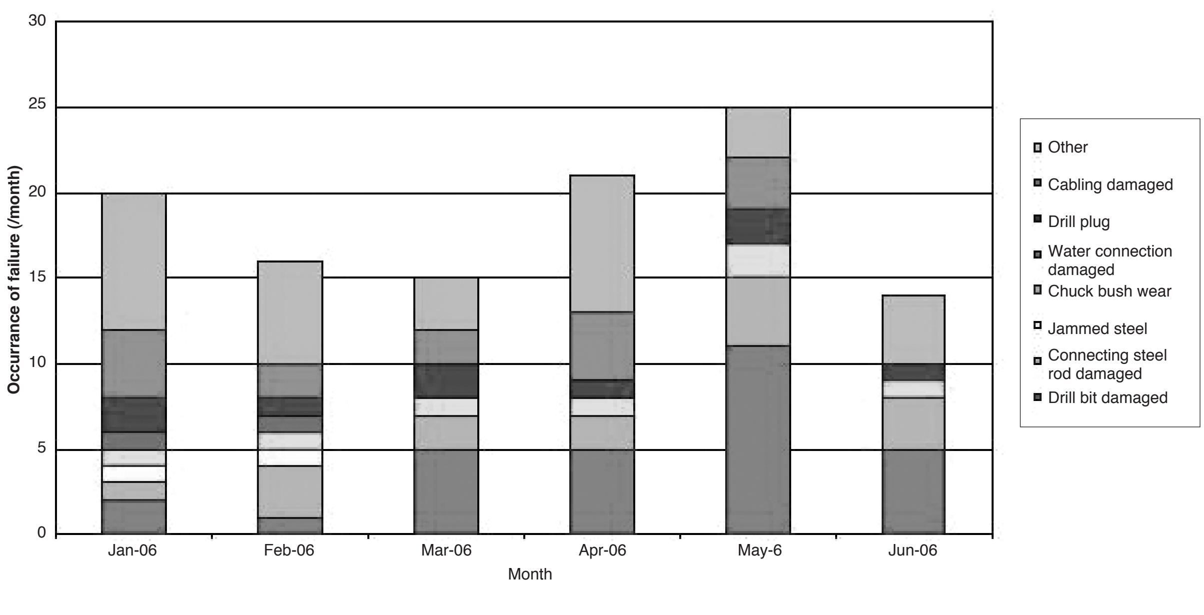

Figure 4. Modes and quantification of failures

The power cables between the manifold box and the drill have been armoured and pretensioned to reduce the number of bending breaks. Cables are often damaged by the scraper. A bracket leads the cable into the drill, thus moderating the angle of bending, and hence breaking of the core wires.

Safety, health and environment

Electric safety devices

The electric rock drill is classified in the Isolation Class 1, with an ingress protection (IP) rating of 66. SANS certification allows this drill to be operated in areas with a risk of explosion. The equipment is impact proof and the electronic control is waterproof. Special designs ensure compliance with mining regulations for its safe use.

The plug connecting the electric rock drill to the manifold box, consists of a 4-pole signal colour plug, known as the Xsafe Plug. The plug is explosion proof and has a pilot wire circuit that is intrinsically safe with a control relay switching system. The manifold box is equipped with four or six socket and plug pairs, rated at 32 Amps with four pins, to allow 'late make and early break' of power supply.

The direct-current (DC) sensitive residual current circuit breaker (RCCB) and an XLP cable armouring provide earth leakage protection rated at a maximum of thirty (30) mA. This value is stipulated in the Government Gazette for industrial purposes and man-access. Daily earth leakage testing must be conducted to ensure the earthing integrity.

Due to an incident, the motorized breaker contactors inside the manifolds were replaced with normal contactor breakers. A feedback circuit was wired in with a timer, so that when the pilot circuit (earth proofing circuit) is broken and the contactors do not open within two seconds, it trips the gully box[3].

Noise exposure

Continuous exposure to noise emission from multiple operating pneumatic rock drills, in the confined reverberating environment, has led to an increased number of compensation claims for noise induced hearing loss (NIHL).

The SANS Code of Practice for the Measurement and Assessment of Occupational Noise for Hearing Conservation Purposes (SANS 083), has permitted noise equivalent exposure (N_{eq}) targets. It is a function of the sound level and the exposure time, namely 85 dB(A)† for an eight-hour period, with a peak sound pressure levels (SPL) of 135 dB(A)[5].

The CSIR completed independent testing to measure SPL in underground conditions, and their attenuation as a function of distance. Values were taken at the rock face in UG2 operations. The muffled compressed air drills emit 108 dB(A) at 350kPa air supply pressure. The SPL increases to 110 dB(A) at 550 kPa. Similar tests for the electric rock drill yielded 102 dB(A)[5]. Since the electric drill is independent of air supply, minimal variation is this value occurred.

† dB(A) is the attenuated equivalent continuous sound level for octave-band centre frequencies

The evaluation of noise emission as a function of distance is equally important. The RDO assistant and the stope crew are likewise vulnerable. The results from the SPL model revealed that overall attenuation of underground noise is a function of frequency, not distance. This contradicts the probability distribution calculations that attenuation of SPL with distance is inversely proportional to the distance from the noise source[5]. The underground mining environment includes reverberation that is not evident in free-field conditions.

The pneumatic rock drill operates between 1600 and 3400 hits/min and is dependent on the supply of air pressure, while the electric drill is rated at 50 Hz and has a percussive output of 1200 to 1680 hits/min. The noise dosage from an electric rock drill without earplugs is less than a pneumatic rock drill with earplugs, due to the noise amplitude and frequency. The electric drills fulfill the requirements set for the year 2013.

Vibration levels

The blow force of the pneumatic rock drill over extended periods of work has exposed the RDO to vibration levels in excess of 16.2 to 19.9 m/s^2. The perpetual operation of this drill has led to symptoms related to Raynaud's phenomenon, generally known as 'white-knuckle' disease or vibration-induced white finger (VWF). The usual symptoms include considerable tingling in the hands and wrists, general whiteness of the fingers, pain and loss of sensation in the fingers. This condition reduces the hands' ability to feel, and hence regulate temperature.

Test results on the vibrations levels of the electric rock drill have indicated values ranging from 7.5 to 9.1 m/s^2 [6]. The intensity is approximately half that of the pneumatic equivalent.

Oil emissions

On a qualitative basis, the RDOs experience a cleaner drilling environment, as observed from the cleanliness of their overalls[1]. There is no inhalation of atomized grease particles. Furthermore, visual communication/'line-of-sight' is improved due to the elimination of a vaporized atmosphere. Additionally, oil has a significant negative outcome on the ore recoveries in the processing plant.

Consideration factors for electric rock drills

Electric drills

Advantages

- Consistent penetration rate
- Easier to handle compared to pneumatic drills
- Fewer drills required for the same production rate
- Only one RDO required for operation
- Lower power and water consumptions (energy saving)
- Independent of compressed air supply
- Quick and easy maintenance
- Longer service intervals
- Repair interval short due to location of workshop underground
- Reduced noise levels and compliance with to legislation
- No oil vapour emissions
- Less machine vibration
- Higher blast yield due to better drilling performance.

Disadvantages

- Unproven longevity
- Consistent performance information not readily obtainable yet
- Minimal introduction of heat into mining environment
- Dependent on specialized/outsourced maintenance/ repair personnel
- Retraining of miners required
- Underground workshop required for maintenance/ repair of leased units
- Single supplier of electric rock drills.

Investigation results

Analyses and interpretation of data

The performance data obtained from the diagnostic equipment of the electric rock drills and case study sheets from the mining operations have been processed to achieve some findings and operational specific statistics. However, due to the diverse geology of the mining operations, other uncontrollable factors and insufficient and erratic information over a short time period, trends cannot yet be established. Some analysis and interpretation were achieved in terms of the parameters shown in Figure 1.

The magnitudes of improvement of the rock drillability and penetration rate differ per operation. However, the factors that influence the results are understood. Although the mining environment is unfavourable, mine plans change, a general decrease in drilling cycle time has been achieved. This is due to the experience and attitude of the RDO, and action taken from the assessment of parameters from diagnostic data. Consequently, the penetration rate has augmented, and at some production panels, the speed has doubled.

The modes of failure indicate that customary wear and subsequent improvement in drill consumables are expected to assist in boosting productivity. The knock-off button and drill steel have been redesigned and strengthened, respectively. The effect on production parameters can be proven only with continuous monthly monitoring and record-keeping.

The potential exists to introduce the electric drill at competing mining operations with better RMR. Drilling in alternate reserves may refine productivity performance, thus eliminating this negative parameter in platinum mines. At these mines too, evaluation will be necessary to allow predictable trends. Continuous analysis and interpretation of the high-level parameters collected from existing operations, will allow the modelling of activities on ‘greenfield’ projects and expansion/replacement projects for development and production.

Layout and design of equipment

The electric drill specifications, electrical supply methodologies and system protection were described. Results from diagnostic data have indicated that modified/adjusted aspects of the modular design enhance reliability, control and safety of the electric rock drill. The potential to extend the life of individual components has also been appraised by investigation of the scheduled service and breakdown rates of the units.

Earth leakage protection has been considered by the inclusion of an additional earth proofing circuit, called a pilot wire. The cable is armoured and pretensioned to reduce damage.

Apart from safety classification and certification, several other protection items have been designed as part of assessing and managing the operational risk. An explosion-proof plug is integral with the drill, and a direct current (DC) sensitive residual current circuit breaker at the manifold box intensifies the safety of the electrical reticulation system.

The safety, health and environment perspectives have been included in the design of the drill. The electric rock drill is quieter and within accepted exposure levels, transmits lower vibrations, and does not emit oil into its surroundings.

Conclusion

The demand for the extraction of larger ore volumes, in an efficient and safe manner, combined with energy-wise methodologies, is the prerequisite for future mining endeavours. The use of electric rock drills is a step towards the target of full ‘electric mining’.

The common goal is to optimize the key performance parameters achieved to date. Direct feedback and more information gathering must be collated to provide better interpretation of results. Commitment and co-operation will result in the improvement of the electric drill product and the development and initiation of additional equipment, to meet the stringent demands of efficacy, safety and energy expenditure in this competitive and global market.

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