

Rock Drills used in South African Mines: a Comparative Study of Noise and Vibration Levels

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Objectives: To compare the noise and vibration levels associated with three hand-held rock drills (pneumatic, hydraulic and electric) currently used in South African mines, and a prototype acoustically shielded self-propelled rock drill.

Methods: Equivalent A-weighted sound pressure levels were recorded on a geometrical grid, using Rion NL-11 and NL-14 sound level meters. Vibration measurements were conducted on the pneumatic, hydraulic and electric drills in accordance with the ISO5349-1 (2001) international standard on human exposure to hand-transmitted vibration, using a Brüel and Kjær UA0894 hand adaptor. PCB Piezo accelerometers were used to measure vibration in three orthogonal directions. No vibration measurements were conducted on the self-propelled drill.

Results: All four drills emitted noise exceeding 85 dB(A). The pneumatic drill reached levels of up to 114 dB(A), while the shielded self-propelled drill almost complied with the 85 dB(A) 8 h exposure limit. Vibration levels of up to 31 m s⁻² were recorded. These levels greatly exceed recommended and legislated levels.

Conclusions: Significant engineering advances will need to be made in the manufacture of rock drills to impact on noise induced hearing loss and hand arm vibration syndrome. Isolating the operator from the drill, as for the self-propelled drill, addresses the problems of both vibration and noise exposure, and is a possible direction for future development.

Keywords: mining; noise; vibration; rock drills; South Africa

INTRODUCTION

Noise induced hearing loss (NIHL) is not confined to the South African mining industry (Nelson *et al.*, 2005). It remains a problem in other countries and is a neglected area for published research in the English language (McBride, 2004).

Almost two decades ago, NIHL in South African gold miners was reported in the medical literature (Hessel and Sluis-Cremer, 1987). Soon after, the South African Chamber of Mines published guidelines for the implementation and control of a hearing conservation programme (HCP) in the mining industry (COMRO, 1988). In 1996 the components of a HCP were included in the Mine Health and Safety Act (Department of Minerals and Energy, 1996).

Workers exposed to noise levels above 82 dB(A) are at risk for NIHL, and those exposed to levels above 90 dB(A) are at high risk (Franz and Phillips, 2001). In 1989 an amendment to the Minerals Act (1989) imposed a limit of 85 dB(A) for exposure to noise in mining operations over a nominal eight hour working day. With the use of personal protective equipment (PPE) and other measures recommended in the Mine Health and Safety Act (Department of Minerals and Energy, 1996), it may be possible to reduce noise exposure to permissible levels. However, it is well established that, despite training in the use of PPE and provision of equipment, many workers do not make proper use of PPE and continue to be exposed to high levels of noise (Phillips and Nelson, 2006). There is, however, no legislation in South Africa for the maximum emission of noise from machinery, and NIHL continues to plague the South African mining industry. In 2005, the Rand Mutual Assurance Company (the insurance

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company that underwrites the compensation and medical costs for mining industry employees injured because of their work) compensated 5 617 NIHL cases (Dr A. Begley, Rand Mutual Assurance Company); the total cost was 135.8 million South African Rands, at an average of 24 177 Rands per NIHL case.

There is no South African legislation pertaining to acceptable vibration levels or vibration exposure limits on mining equipment. The European Community Directive 2002/44/EC specifies a daily exposure limit of 5 m s^{-2} standardised to an 8 h reference period, and an action value of 2.5 m s^{-2} . A South African study published in 1998 recorded vibration levels on rock drill handles of 24 m s^{-2} (van Niekerk *et al.*, 1998). In 2002, hand arm vibration syndrome (HAVS) was described for the first time in South African miners (Nyantumbu *et al.*, 2002, 2006). The prevalence of HAVS in 156 vibration-exposed gold miners was 15%; all cases occurred in miners who had operated rock drills. In addition, 8% of vibration-exposed miners had carpal tunnel syndrome (CTS) of which 5% occurred simultaneously with HAVS. CTS is also associated with exposure to vibration (Wieslander *et al.*, 1989).

It is always better to effect engineering solutions to reduce a hazard at source, rather than relying on PPE to protect workers. Recently, the South African Mine Health and Safety Council (MHSC), a tripartite organisation, comprising representatives of state, labour and employer, signed an agreement with the mining industry to achieve milestones in the field of NIHL. These milestones include the goal of ensuring that, after December 2008, there will be no deterioration in hearing $>10\%$ amongst occupationally exposed individuals. After December 2013, in addition to the 85 dB(A) human exposure limit, the total sound pressure level associated with all equipment, or any individual piece of equipment, must not exceed 110 dB(A) (Mine Health and Safety Council, 2005). No similar action has been instituted for vibration.

The MHSC, together with rock drill manufacturers, has been working to produce a quieter, self-propelled rock drill that does not require the operator to guide it (Otterman *et al.*, 2001). This drill comprises a standard pneumatic drill on guide rails enclosed within a sealed tube, and incorporating an automated thrusting mechanism. The acoustic shielding significantly reduces noise levels. At the same time, since the operator does not come into contact with the drill in operation, there is no transmission of vibration to the hands.

To investigate what is currently available to the mining industry, the MHSC commissioned a study into noise and vibration levels associated with rock drills. This study compared the noise and vibration levels recorded during the operation of three types of rock drills currently used in the mining industry, and the prototype self-propelled drill. This was the



Fig. 1. Self-propelled drill in the above-ground artificial stope.

first time, as far as we are aware, that manufacturers allowed their products to be tested in a direct comparative way. This paper presents and evaluates the results from this study.

METHODS

The testing was carried out during the course of one day in an above-ground artificial stope (Fig. 1) that was developed to simplify and standardise various aspects of testing. The stope comprises a cast concrete floor and adjustable height concrete slab roof, to simulate various stope heights. The floor and roof are both profiled to correspond to typical rock conditions in South African stopes. The artificial stope was developed to reduce the logistical burden for some categories of routine ‘underground’ testing.

Four rock drills in six configurations were tested, viz. the prototype self-propelled drill developed by the MHSC with standard and clad drill steels, an electric drill, a hydraulic drill, and a pneumatic drill with standard and muffled configurations. The pneumatic, hydraulic and electric drills tested are in current use. The pneumatic drill that was tested has been the ‘industry standard’ since the late 1970s. The other two types are used to a lesser extent. The electric drill was adopted by the industry in the last few years.

The drills were all operated by representatives of the suppliers. The air pressure for the pneumatic drills was controlled at $\sim 550 \text{ kPa}$, the water pressure for the hydraulic drill was between 12 and 18 MPa and the electrical supply for the electric drill was 220 V.

The rock penetration rate for each drill configuration was determined by recording the times required to penetrate 0.5 m into a block of norite rock.

A-weighted equivalent sound pressure levels (L_{Aeq}) were recorded for all six configurations on a geometrical grid, over a minimum period of 20 s, using two sound level meters, viz. a Rion NL-11 and

Rion NL-14. These sound pressure levels were recorded at 28 pre-determined positions on a circular grid around the drill. During each of these measurements it was endeavoured to keep the drilling conditions as steady as possible in order to get consistent and comparable measurements at the maximum rate of penetration. To characterise the sound pressure field, the L_{Aeq} sound pressure level was used as representative metric. No attempt was made to factor in the effects of turn-around time between holes or the overall drilled distance during a shift on the 8-hour noise exposure level, because of the widely varying conditions underground, which affect these periods significantly. The results presented here should therefore be considered to provide an indication of the comparative sound pressure levels under steady drilling conditions, rather than as an indicator of the noise exposure.

No vibration measurements were conducted on the self-propelled drill as it is not designed to be hand-held. On the other drills, the vibration measurements were conducted in accordance with ISO5349-1 (2001), using a Brüel and Kjær UA0894 hand adaptor. This adaptor was employed as an alternative to mechanical filters and is indispensable for measuring under the highly impulsive conditions experienced on the rock drills. High levels of vibration may occur here at frequencies way beyond the ISO 5349-1 band of interest, and may cause saturation of the electronics or even failure of the transducers. PCB Piezo accelerometers were used to measure vibration in three orthogonal directions. The measured acceleration histories were subsequently recorded on a SigLab 20-42 analyser and post-processed to find the relevant weighted root mean squared (RMS) accelerations, using software developed for this purpose.

RESULTS

The hydraulic drill achieved the greatest penetration rate of 600 mm min^{-1} (Table 1). The shielded self-propelled drill and the pneumatic drill performed similarly; the electric drill had the lowest penetration rate of 130 mm min^{-1} .

Measured L_{Aeq} sound pressure level contours for four of the configurations are depicted in Fig. 2. In these diagrams the contour lines are spaced at 1 dB(A), and a consistent grey scale is used; the darker areas represent higher sound pressure levels. The contours for the self-propelled drill with the standard and cladded drill steels were very similar, while the contours for the pneumatic drill standard and muffled configurations were similar in nature, albeit typically some 3–4 dB(A) lower for the muffled configuration. These contours for the muffled system are therefore not reproduced here. For a quantitative indication of the sound pressure levels,

Table 1. Drill penetration rates for the six configurations of rock drills

Configuration	Penetration rate (mm min^{-1})
Self-propelled drill with standard drill steel	300–400
Self-propelled drill with cladded drill steel	300
Pneumatic drill: standard configuration	350
Pneumatic drill: muffled configuration	395
Hydraulic drill	600
Electric drill	130

the actual measurements at three positions: about half a meter behind, close to the operator's right ear, and at $45^\circ \sim 3 \text{ m}$ to the right and rear of the operator, are reported in Table 2.

The self-propelled drill produced by far the lowest sound pressure levels. These levels were well within reach of the 85 dB(A) limit even if the drill was to operate continuously for an 8-h period.

The standard conventional pneumatic drill generated the highest noise levels—as high as 114 dB(A) at some positions. As indicated above, muffling reduced the sound pressure levels marginally, by $\sim 3\text{--}4 \text{ dB(A)}$.

The evaluation of human exposure to hand-transmitted vibration entails determination of a frequency-weighted RMS acceleration, and combines the weighted acceleration along three orthogonal axes a_{hwX} , a_{hwY} and a_{hwZ} in an overall a_{hv} value (ISO 5349-1, 2001) which is defined as the root-sum-of-squares of the three component values. These values are expressed in metres per second square (m s^{-2}). A basicentric coordinate system is used with z corresponding to drill feed direction, x perpendicular to z and essentially in the down direction, and y perpendicular to z in the lateral direction.

The vibration levels recorded for the standard configurations of three drill types (excluding the self-propelled drill) are recorded in Table 3. Vibration from the hydraulic drill was particularly high at 31.0 m s^{-2} . The vibration from the pneumatic drill was lower at 21.9 m s^{-2} . As one would expect, muffling made no difference to the vibration measured. The lowest level of vibration was recorded for the electric drill, at 9.2 m s^{-2} .

Table 4 summarises the penetration rates, and noise and vibration levels for all the drill configurations. In summary, while the hydraulic drill had the highest penetration rate (600 mm min^{-1}), it produced medium to high sound pressure levels [103.4 dB(A)], and the highest vibration levels (31.0 m s^{-2}). The electric drill caused the lowest vibration levels (9.2 m s^{-2}) and medium sound pressure levels [94.7 dB(A)] but the penetration rates were low (130 mm min^{-1}). The pneumatic drill had medium

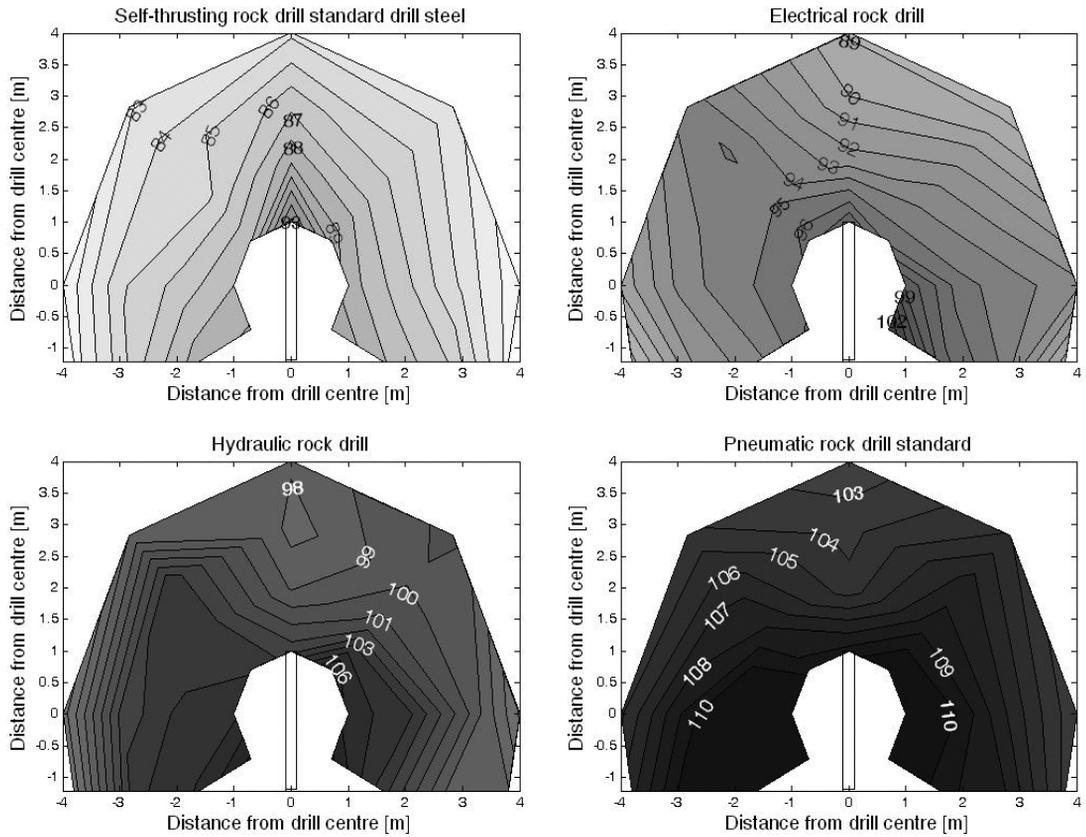


Fig. 2. Measured sound pressure levels around the drills.

Table 2. Sound pressure levels at the three grid positions

Configuration	Behind operator [dB(A)]	Right of the operator [dB(A)]	Right further back [dB(A)]
Self-propelled drill with standard drill steel	88.7	84.9	82.9
Self-propelled drill with cladded drill steel	84.1	86.1	84.1
Pneumatic drill: standard configuration	104.4	107.9	104.2
Pneumatic drill: muffled configuration	100.5	103.8	98.1
Hydraulic drill	98.9	103.4	98.1
Electric drill	92.4	94.7	94.6

Table 3. Vibration levels of three rock drills (standard configurations): weighted RMS

Drill	a_{hw_x} ($m s^{-2}$)	a_{hw_y} ($m s^{-2}$)	a_{hw_z} ($m s^{-2}$)	a_{hv} ($m s^{-2}$)
Pneumatic drill	10.9	6.0	18.0	21.9
Hydraulic drill	13.3	9.7	26.3	31.0
Electric drill	6.0	4.7	5.2	9.2

penetration rates (350 mm min^{-1}), and medium noise [$\sim 105 \text{ dB(A)}$]; vibration levels were high (21.9 m s^{-2}). The self-propelled drill was the quietest drill with the two configurations at 84.9 and 86.1 dB(A),

respectively, with medium penetration rates of $300\text{--}400 \text{ mm min}^{-1}$.

DISCUSSION AND CONCLUSIONS

The present noise exposure limit specified in South African mining regulations is 85 dB(A) over an 8-h working day but this applies to the levels to which workers are exposed (with PPE, if necessary) rather than the levels emitted by the machines. The noise levels emitted by individual drills in this study were, in most cases, below 110 dB(A) during periods of steady drilling. Thus, the MHSC's milestone to reduce the total noise emitted by all

Table 4. Summary of penetration, noise and vibration measurements for each rock drill configuration

Configuration	Penetration rate (mm min ⁻¹)	Noise ^a [dB(A)]	Vibration ^b (m s ⁻²)
Self-propelled drill with standard drill steel	300–400	84.9	Not measured
Self-propelled drill with cladded drill steel	300	86.1	Not measured
Pneumatic drill: standard configuration	350	107.9	21.9
Pneumatic drill: muffled configuration	395	103.8	21.9
Hydraulic drill	600	103.4	31.0
Electric drill	130	94.7	9.2

^a L_{Aeq} at point 2.

^bWeighted acceleration a_{hv} .

equipment installed in any workplace to below 110 dB(A) should be possible to meet using technology that is currently available. Assuming that the drill typically operates for 2 h per shift (van Niekerk *et al.*, 1998) and, bearing in mind that every 3 dB(A) increase in noise level requires a 50% reduction in exposure time, a 2 h shift equates to maximum unprotected levels of around 91 dB(A). It is therefore clear from Fig. 2 and Table 2 that typical noise levels on conventional equipment are still too high. This emphasizes the need for further development on alternatives such as electrical drilling and the self-propelled acoustically shielded drill.

Vibration levels as high as 31 m s⁻² (measured on the hydraulic drill handle) were measured in this study. The lowest vibration levels were recorded from the electric drill. However, even these 'lower' levels far exceeded the European Community Directive recommended action limit of 2.5 m s⁻² for hand-held vibrating tools. Although the actual time that the operator is in physical contact with the drill can be assumed to be <2 h per day (van Niekerk *et al.*, 1998), it is clear that the vibrations levels are excessive.

Despite legislated noise limits and the requirement for HCPs, the prevalence of NIHL in the South African mining industry remains at an unacceptable level. Muffling reduces sound pressure levels by up to 4 dB(A) and further developments along these lines are likely to lead to only marginal improvements. A solution to both the noise and vibration problems would appear to be the isolation of the operator from the drill as in the case of the shielded self-propelled rock drill. However, the drilling machine is large and cumbersome and cannot be easily manoeuvred, especially in the confined spaces underground in which much drilling takes place. It is thus not currently in use in South African mines. The reduced noise exposure and total absence of transmission of vibration through the hands suggest that this fundamentally different, hands-off approach to drilling should, however, be further explored as a direction for future development.

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