A technique for estimating the sound power level radiated by pneumatic rock drills and the evaluation of a CSIR prototype rock drill with engineering noise controls

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Synopsis

Overexposure to noise remains a widespread, serious health hazard in the US mining and other industries despite 25 years of regulation. Most categories of illnesses and injuries associated with mining have improved, with the exception of hearing loss. The drilling of rock in a confined work environment contributes to high levels of noise exposure in mining.

The National Institute for Occupational Safety and Health (NIOSH) is conducting research to reduce the noise exposures of jackleg drill operators and to prevent additional cases of noise induced hearing loss (NIHL) by developing and evaluating low-cost retrofit noise controls for equipment. This report describes the procedure for the measurement and reporting of noise from portable pneumatic tools such as jackleg drills. The technique used in this research allows for the determination of the source A-weighted sound power levels and the radiation patterns in octave and 1/3 octave bands. Overall sound power level is also determined. This paper also reports the results obtained by using this procedure to evaluate a SECO S215 standard production drill and a CSIR Miningtek prototype rock drill incorporating engineering noise control measures.

It was found that by using the manufacture's recommended operating pressure of 496 kPa (72 psi) that the CSIR prototype's sound power was 10 dB(A) less then that of the SECO S215.

Introduction

The pneumatic rock drill is one of the most severe noise sources in mining operations. The operation of these drills produces A-weighted noise levels in the range of 100 to 120 dB at the operator location. These sound levels are unacceptable since they are high enough to cause NIHL. This type of rock drill is powered by compressed air which is discharged at 1500 to 2500 cycles per minute causing a series of noise pulses.

Several investigations[1–3] have determined that the noise sources of pneumatic rock drills can be classified into three areas: exhaust noise, drill steel noise and mechanical noise from the drill components. The exhaust noise is generated by spent air passing from the exhaust opening at high velocity and mixing with the ambient air. Also, the exhaust air can create mechanical noise from within the drill. The drill steel noise is caused by the vibration generated by the impact between the drill piston and the drill steel. Also, the noise of the drill bit impacting against the rock causes the drill steel to ring. Further mechanical noise is generated by the rotation mechanism and the interaction of internal parts.

While each of the significant noise sources within a conventional rock drilling system has been addressed in previous work by many researchers, few of the solutions have been successfully implemented. However, previous work has shown that the problems that restricted implementation of these solutions can be resolved if the thrust is directed along the axis of the drill, i.e. 'in-line' thrusting. According to experiment and underground measurements 'in-line' thrust can provide for performance increases of up to 100 per cent, as well as facilitate the drilling of straight holes, thereby minimizing contact between the drill steel and the hole. In order to provide 'in-line' thrusting a concept was developed by which a rock drill with minor modifications became a piston within what is effectively an enlarged thrust-leg tube.

Noise control of existing pneumatic drills is difficult to accomplish. Factors that have to be considered are cost, performance, and weight. Muffling of exhaust has been done to varying degrees for noise attenuation but is only marginally successful. Because of the exposure of the operator to high noise levels, the need exists for quieter pneumatic drills.

This report documents the evaluation procedure and the evaluation performed by NIOSH on a SECO S215 rock drill and a SECO S215 rock drill with noise controls developed by CSIR Miningtek[3]. This work is in support of

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the NIOSH mission to reduce NIHL among mineworkers. NIOSH has recognized NIHL as one of the 10 leading work-related diseases and injuries in the United States, and has emphasized its importance as one of the critical areas expressed in the National Occupational Research Agenda.

Measurement method

The method used in this evaluation consisted of sound pressure level measurements on a surface enveloping the noise source, i.e. the enveloping surface method. The acoustic environment for the measurements of the source was a free-field over a reflecting plane. The measurements were then used to estimate the sound power level at each frequency band of interest. The overall A-weighted sound power level was then determined by logarithmically adding the sound power levels in each frequency band. The surface enveloping method allows for three grades of accuracy: precision grade, engineering grade, and survey grade. Engineering grade accuracy was implemented in this evaluation following ISO 37444 (see Appendix A). For the sake of completeness, Table I presents the general characteristics of the engineering grade accuracy used in this evaluation.

As specified in ISO 3744, a hypothetical rectangular parallelepiped reference box was first defined. The reference box used was the smallest one that completely enclosed the drill ignoring protruding elements that are not significant noise radiators. The reference box terminated on the reflecting floor surface.

Since the noise measurements were performed while drilling, the rock or block tested was considered as part of the source when defining the reference box. On the other hand, air and water hoses were not included as part of the source.

The measurement surface was also a hypothetical rectangular parallelepiped whose sides were parallel to the reference box. The measurement surface was defined by the measurement distance d, which is the normal distance between the reference and measurement box surfaces. The measurement surface also terminated on the reflecting floor surface. The measurement distance d can be 0.25, 0.5, 1, 2, 4, or 8 metres with a preferred distance of 1 metre. Figure 1 shows an example of the reference and measurement surfaces. The dimensions of the measurement surface are length $2a$, width $2b$, and height c.

The microphones were positioned on the measurement surface. Nine microphones were used which satisfied the minimum number of microphones requirement for engineering grade.

The position of the microphones is a function of the size and shape of the reference box. The procedure for the placement of the microphones was as follows:

- Each side of the surface measurement box was subdivided by the minimum number of equal-sized rectangular areas with a maximum length of side ≤ $3d$.
- Microphones were then placed at the centre and each corner of each of the equal-sized rectangular areas. Microphones were not placed at the corners on the reflecting plane.

Microphone locations that are in the direct path of the air exhaust outlet of the pneumatic machine were avoided since they can lead to erroneous measurements. Figure 2 shows the nine microphone locations on the measurement surface used in this study. Microphone 10 is shown in Figure 2, located near the operator's ear, but this microphone was not used in this study. This paper documents only the evaluation and the estimated sound power levels radiated by a Boart Longyear SECO S215 rock drill and a Boart Longyear SECO S215 rock drill with noise controls developed by CSIR Miningtek.

Table I

Characteristics of engineering Grade 2 accuracy enveloping surface method to estimate sound power level

Parameter	Engineering Grade 2 accuracy
Volume of noise source	No restrictions—limited by available test environment
Test environment	Outdoors or indoors
Criterion for suitability of test environment	$K_2 \leq 2$ dB in each frequency band
Characteristics of noise	Any (broadband, narrow-band, discrete frequency, steady, non-steady, impulsive)
Limitation of background noise	$\Delta L \geq 6$ dB in each frequency band $K_1 \leq 1.3$ dB
Number of measuring points	≥ 9
Instrumentation	Complying with type 1
Precision of method for determining L_{WA} expressed as standard deviation of reproducibility	$\sigma \leq 1.5$ dB

K_1 = correction factor for background noise
K_2 = test environment correction factor based on room absorption

Measurements

For pneumatic rock drills, the major noise sources are the drill itself and the drill steel. Therefore, the measurements were conducted while drilling into rock or a concrete block[5]. In order to assure repeatable measurements, the starting time of the noise measurement was taken as the time when the

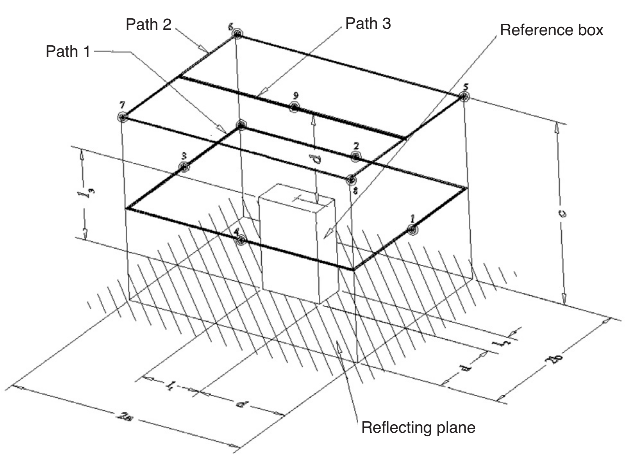

Figure 1—Example of reference and measurement parallelepiped surfaces. • Microphones

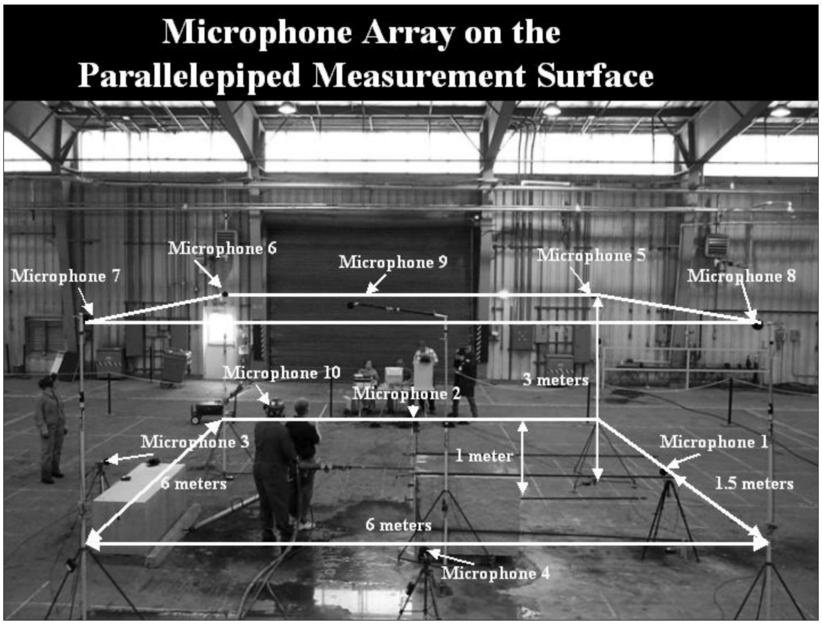

Figure 2—The microphone array setup for the parallelepiped measurement surface

drill bit was at least 0.1 m (3.9 inches) into the rock or concrete. The measurement time was at least 15 seconds while the drill bit was penetrating the rock or concrete block[5]. If feasible, the measurement time for frequency bands ≤ 160 Hz were at least 30 seconds.

The time-average sound pressure level measurements were performed in octave or 1/3 octave bands. The octave measurements at least included all the bands between 63 and 8000 Hz, i.e. bands numbers 18, 21, 24... and 39. The 1/3-octave measurements at least included all the bands between 50 and 10000 Hz, i.e. band numbers 17 through 40. The overall time-average sound pressure level (full frequency range) was also measured.

The time-average background noise level was recorded in all the frequency bands selected for measurement at all measurement locations. The overall background sound level noise was also recorded.

All sound pressure level measurements were A-weighted. The recorded signals were post processed and the sound power levels were calculated for each test.

Test procedure

Two SECO S215 rock drills were tested at NIOSH's Pittsburgh Research Laboratory (see Figures 2, 3, and 4). The testing facility used at Pittsburgh Research Laboratory was essentially a free-field environment over a reflecting plane in a large bay area. Drill one was a SECO S215 standard production rock drill with a SECO air leg. Figure 3 shows the drill being evaluated.

Drill two was the CSIR prototype drill developed by CSIR Miningtek. The drill was a SECO S215 with engineering noise control modifications resulting in an enlarged thrust-leg tube. Details of the engineering noise control modifications are not available at this time. Figure 4 shows the prototype drill ready for evaluation.

Figure 3—Drilling with the SECO S215

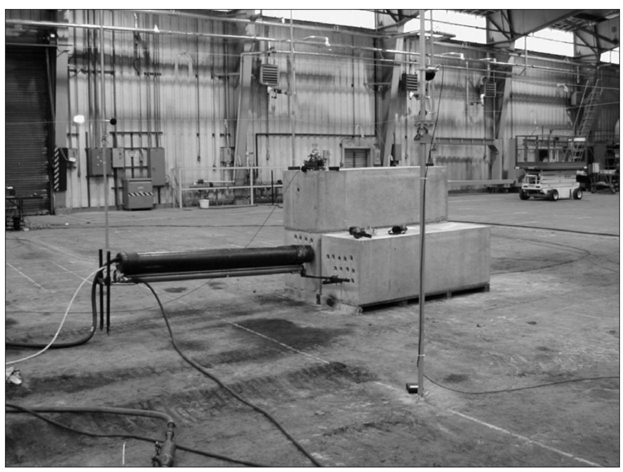

Figure 4—CSIR modified drill

Both drills were tested using a button bit with a 1.22 metres (4 ft.) drill steel under normal loading. A controlled operation was used in order that repeatability could be achieved. Because rocks are a natural material, their compression strengths may vary. This makes test repeatability difficult to achieve. Granite was procured with a consistent compressive strength of 165.473 MPa (24000 psi). Also, a concrete block having a consistent compressive strength of 41.368 MPa (6000 psi) was manufactured. It should be noted that the button bit is not typically used for concrete drilling, but was used in testing to maintain bit consistency during drilling[6]. Also, having two different media for drilling provided additional information on the penetration rate with respect to noise. The drill being tested should always be tested in the medium it was designed for in order to validate the drill penetration rate. Testing in soft and hard media allows for comparison with other drills at a later time. The SECO S215 is designed for a hard medium, such as granite.

The measuring system consisted of 9 microphones and a Racal A480 Digital Tape Recording System, which is capable of performing measurements in 1/3 octave bands. The recorded sound pressures were post-processed using commercially available software to determine the sound pressure levels in 1/3 octave bands. The tests were set-up according to ISO 3744 as outlined in the previous sections. Figure 2 shows an example of a typical set-up. For any given test, all measurements were made simultaneously.

The US Department of Trade and Industry's 'A Guide for Manufacturers to the Evaluation of Uncertainties'[7] was used as a guideline when formulating the test plan for determining the sound power levels of both drills to ensure that repeatable results would be obtained. Therefore, the test plan consisted of 5 measurements for each test parametre unless 2 out of 3 measurements were within 1 dB of each other at each microphone location. In that case, the remaining two measurements were not conducted. The parametres that were varied for the jack leg drill consisted of thrust pressure and water flow rate. The factory recommended thrust pressure and water flow rate were 496 kPa (72 psi) and 7.57 litres/minute (2 gallons / minute). In order to evaluate how the drill would perform in overload and underload conditions, the drill was tested at ± 69 kPa (10 psi) and ± 3.79 litres/minute (1 gallon/minute). Therefore, 3 thrust pressure levels and 3 water pressure levels were used. This resulted in 9 different combinations of test parametres with 5 measurements for each combination totaling 45 measurements for each drill and for each drilling material. In addition to the drilling tests, non-drilling tests were also conducted. These tests consisted of running the drill without drilling at the different thrust pressures without water.

Test results

Sound levels heard by a drill operator are determined both by the sound power radiated by the drill and by the acoustic characteristics of the mine environment. The sound power is the quantity of most interest. Once the sound power is known, one can predict the sound level that the operator is exposed to based on the acoustic characteristics of the environment. Sound power gives a direct comparison of noise generated by any drill tested under the same conditions.

The sound power radiated by the SECO S215 rock drill and the modified SECO S215 rock drill (CSIR prototype) were determined for normal operating conditions. For each test hole drilled, sound power and the penetration rate were determined. Since the test results showed an overall environmental K factor of -.31, -.31 was added to the surface sound pressure level. Calculations of surface sound pressure level were determined from the equation below:

$$L_{pf} = L'_p - K_1 - K_2$$

L_{pf} = surface sound pressure level
L'_p = measured sound pressure level
K_1 = correction factor for background noise
K_2 = test environment correction factor based on room absorption

The surface sound pressure level was then used to calculate the sound power level.

Also, it should be noted that the water amount used for flushing the material out of the hole had no effect on noise levels or penetration rates. The goal was to compare both drills under the same conditions for sound power and performance.

Results for drilling in concrete demonstrated that the CSIR prototype sound power was reduced by 10 dB(A) as compared to the SECO S215. This is shown in Figure 5. However, the penetration rate or performance of the CSIR prototype decreased for all operating pressures. This can be seen in Figure 6.

Using the manufacturer's recommended operating pressures of 496 kPa (72 psi), for the SECO S215, the tests results showed that the CSIR prototype sound power level was 10dB (A) less then the SECO S215. The penetration rate

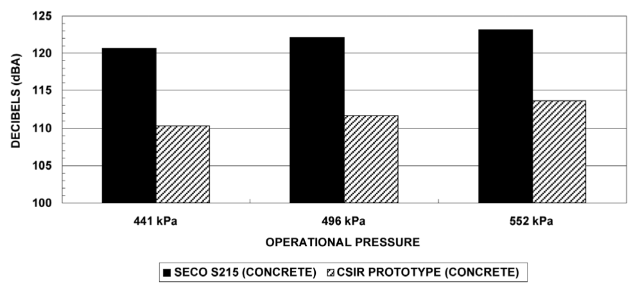

Figure 5—Sound power comparisons while drilling in concrete

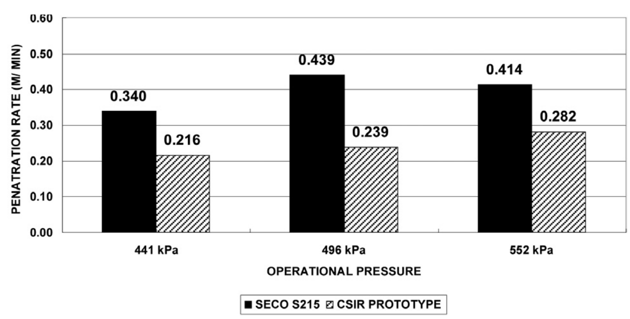

Figure 6—Performance comparisons while drilling in concrete

also dropped for the CSIR prototype by almost .203 metres per minute (8 inches per minute). However, it should be noted that the SECO S215 was designed for a hard medium and not a soft medium like concrete.

Results for drilling in granite indicate that the CSIR prototype's sound power level was reduced by 10 dB(A) as compared to the SECO S215 (Figure 7). However, the penetration rate of the CSIR prototype did not drop as much as when drilling in concrete and, in fact, it outperformed the SECO S215 at 552 kPa(80 psi). This can be seen in Figure 8.

In summary, it was found that by using the manufacturer's recommended operating pressure of 496 kPa (72 psi), the CSIR prototype's sound power was 10 dB(A) less then that of the SECO S215. Also, the penetration rates of both drills were within 6% of each other. This indicates that the noise control was effective without sacrificing performance. By increasing the thrust pressure to 552 kPa (80 psi) the CSIR prototype actually outperformed the SECO S215 and the sound power level was still reduced by 10 dB(A).

While conducting the tests on the CSIR prototype, it was noted that the type of oil used with the automatic oiler was critical to the proper operation of the drill. The type of oil required is dependent on the ambient temperature. If the wrong oil was used, the drill would stall. The CSIR prototype was cumbersome and required two people to set it up. First, a support hole for the drill had to be drilled into the working face. The two people then had to manoeuvre the drill in order to insert the support rod of the drill into the newly drilled support hole. The feed pressure to the CSIR prototype was critical to its proper operation. Approximately 69 to 103 kPa (10 to 15 psi) was required. When the feed pressure exceeded 103 kPa (15 psi) the drill stalled. When the feed pressure was too low, it would not drill.

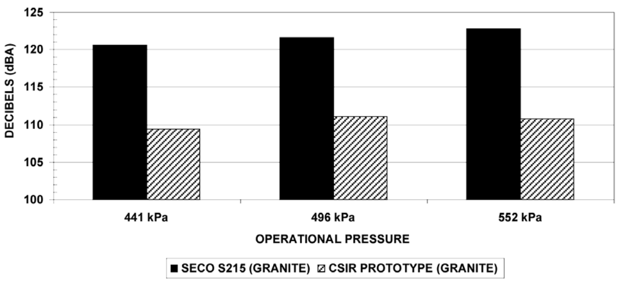

Figure 7—Sound power comparisons while drilling in granite

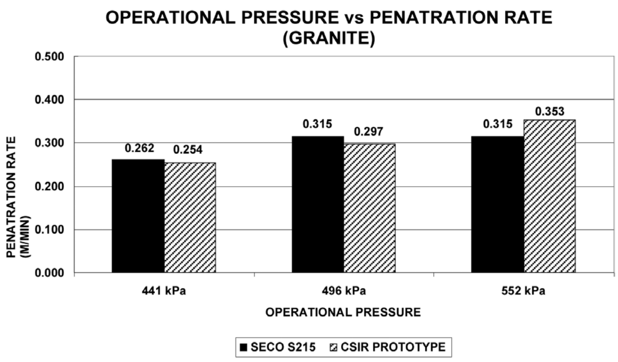

Figure 8—Performance comparisons while drilling in granite

Conclusions

Test results demonstrated that the flow rate of the water used for flushing the material out of the hole had no effect on sound power level or the penetration rate of either drill. The SECO S215 performed best, having a penetration rate of 0.439 metres/minute (17.3 inches/minute) while drilling in concrete at the recommended operating pressure of 496 kPa (72 psi). However, when drilling in granite, the SECO S215 penetration rate dropped to 0.315 metres/minute (12.4 inches / minute) for both operating pressures of 496 (72 psi) and 552 kPa.(80 psi). Granite is a hard medium and is more representative of the medium for which the SECO S215 rock drills were designed. The sound power level of the SECO S215 had little change for any of the tests ranging from 120 to 123 dB(A).

The CSIR prototype performed best while drilling in granite. When drilling in granite with an operating pressure of 552 kPa (80 psi), it out performed the SECO S215 with a penetration rate of 0.353 metres/minute (13.9 inches/ minute) as compared to 0.315 metres/minute (12.4 inches/minute) for the SECO S215. The sound power level for the CSIR prototype was consistently 10 dB(A) below that of the SECO S215 with the same operating conditions. It appears that the CSIR prototype is potentially a viable engineering noise control for rock drills. However, there are some issues that need to be addressed: the set-up requirements and the feed pressure. The CSIR prototype is too difficult for one person to operate and would take too long to set up underground. The feed pressure needs to have a presetting range for the operator based on the material conditions.

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