Sound power level study of a roof bolter

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) has initiated a study of a roof bolter to reduce noise exposure to mine roof-bolter operators. An important segment of this research entails determining the affect of various drilling configurations on the performance (penetration rate) and sound power emissions when drilling into granite. Test conditions included using various combinations of rotational speeds and thrusts, using 2.54- and 3.49-mm- (1- and 1 3/8-in.-) diameter hexagonal and round drill steels, using vacuum and wet conditions and using drill media of differing compressive strengths. This paper details the affects of each of these variables on the performance and sound power level emission. When drilling into granite, it was found that wet drilling generated lower sound power levels and performed better than vacuum drilling.

Introduction

Noise is one of the most pervasive health hazards in mining. NIOSH identified occupational noise-induced hearing loss (NIHL) as one of the ten leading work-related diseases and injuries. Mine Safety and Health Administration coal noise sample data (Title 30 CFR, Part 62) collected from 2000 to 2002 show that 65% of the equipment whose operators exceeded 100% dosage comprise only seven different types of machines: auger miners, bulldozers, continuous miners, front end loaders, roof bolters, shuttle cars (electric) and trucks (MSHA, 2000-2002). In addition, the MSHA data indicate that the roof bolter is third among all the equipment and second among equipment in underground coal mines whose operators exceed 100% dosage (Fig. 1).

This paper presents results from a project that forms part of the latest effort by NIOSH's Pittsburgh Research Laboratory (PRL) to control noise exposure in mining environments. Specifically, this paper concentrates on the noise emissions during the drilling cycle of a roof-bolting machine. This information is available for reference to designers of mining equipment, mining companies and MSHA.

Background

Underground drilling is subject to many variables that can affect noise emissions. Some of these variables, such as the acoustic environment, the geometry and composition of the surfaces, the mine shape and the compressive strength of the drill medium, cannot be controlled. Other variables such as drill steel shape and bit size are controlled by the operator. The acoustic environment that the mining machines operate in is a critical factor in influencing the sound pressure levels to which workers are exposed. Underground mines are enclosed areas with reverberant sound fields. The geometry and the composition of the surfaces influence the overall sound level by reflecting or absorbing the incident sound energy. The compressive strength of the media being drilled affects the acoustic absorption properties of the mine environment. Harder media, with compressive strengths above 138 MPa (20,000 psi), reflect more acoustic energy than softer media, i.e., less than 83 MPa (12,000 psi) compressive strength.

The operator is responsible for controlling the roof bolter, which may directly or indirectly affect the overall noise level generated while drilling. Thrust levels and rotation speeds supplied to the drill will also affect the sound power emissions. Variations of the thrust and rotation speed in different media will affect the performance of the drill, which is indirectly related to the sound power level emissions. For instance, stalling or jamming of the drill bit because of incorrect thrust levels or rotation speeds will create an increased sound power emission. Using the manufacturers recommended settings of the roof bolter for the drill media would enhance the performance of the drill, penetration rate and directly affect the sound pressure levels to which workers are exposed.

The roof bolter has several noise sources that may be considered worthy of examination. These include the vacuum pump, hydraulic pumps, drill chuck, drill steel and drill bit. The vacuum pump, hydraulic pumps and drill chuck will vary for different drill manufacturers. Both vacuum and hydraulic

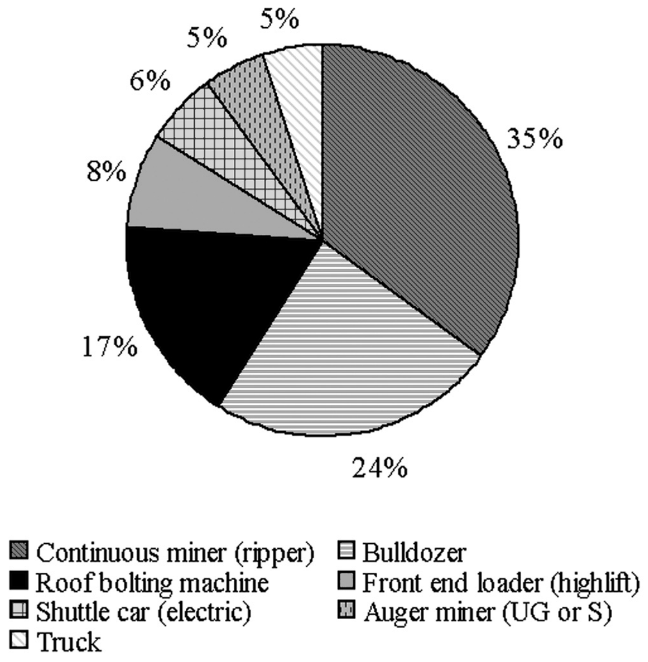

Figure 1 — MSHA coal noise sample data — percentage of equipment whose operators exceeded 100% dose.

Table 1 — Estimated standard deviation of reproducibility of sound power levels.

Octave-band center frequency, Hz	Standard deviation of reproducibility, σ_R
125	5.0
250	3.0
500 through 4,000	2.0
8,000	3.0
A-weighted	2.0*

*Applicable to a relatively flat spectrum from 100 through 10 kHz.

pumps contributes some to overall noise emissions. However, early tests at PRL confirmed that the hydraulic and vacuum pumps are not a major noise source for roof bolters.

Drill steels are manufactured either in hexagonal or round shapes. The steel can be manufactured at any length, but typical lengths are 1.2, 1.8 and 2.4 m (4, 6 and 8 ft). Bits are available in several types, usually designed for either wet or vacuum drilling. The sharpness of the drill bit will have considerable effect on the performance of the bolter, which will influence the sound power levels generated. Wet drilling, as opposed to vacuum, was expected to generate a lower sound power level because water attenuates higher frequency noise.

These concerns prompted NIOSH to perform research to determine the effects of each of these factors on the performance and sound power emissions when drilling.

Technical approach

Sound levels to which roof bolter operators are exposed are determined by the sound power radiated from the drilling process and by the acoustic characteristics of the mine environment. The sound power is the quantity of most interest because it is a fundamental property of the drilling process and can be used for comparative purposes of differing drilling configurations independent of acoustical environmental conditions in any specific mine environment. Additionally, once the sound power level is determined, it is possible to predict the sound pressure level that the operator will be exposed to once the acoustic characteristics of the mine environment are understood. Sound level prediction research of this type is currently in development at PRL and is beyond the scope of this paper.

Test plan

Given the variation in underground mines, both geometrical and acoustical, it is difficult to achieve uniform test conditions. Therefore, testing was conducted in a reverberation chamber at PRL. This allows sound power-level determination in a known acoustic environment, and the results are independent of the variables associated with the acoustic properties of underground mines.

Environmental conditions in the test chamber are controlled so as to not influence test results in excess of the uncertainty stated below. The key environmental condition to control is relative humidity, which is controlled via humidifiers. The relative humidity is maintained above 65% at all times, so as to not affect the data at higher frequencies, i.e., 1,000 Hz or greater.

A survey of acoustics standards detailing accepted procedures for determining sound power levels in hard walled or reverberant test chambers led to the selection of ISO 3743-2 (ISO, 1994) as the industry standard around which the testing was based. The objective is to ensure that sound power determinations are sufficiently repeatable to allow detection of changes in emissions due to the various test conditions and sufficiently reproducible to allow the data to be used for meaningful sound pressure level prediction in real mine environments. Measurement repeatability is a measure of the ability of laboratory to get the same result on the same test specimen within the laboratory and is determined through repeatability studies conducted by the laboratory. Measurement reproducibility is a measure of the uncertainly associated with test results from different laboratories and is stated in the test standard based on round robin studies conducted amongst acoustics laboratories.

The ISO 3743-2 test method has a stated standard deviation of reproducibility of 2.0 dBA, with uncertainty as a function of frequency as shown in Table 1. Internal quality-assurance studies in the PRL reverberant test facility for well-behaved sources indicated that the standard deviation of repeatability in the laboratory is on the order of 0.25 dBA. As the 95% uncertainly interval associated with both the repeatability and reproducibility of the method is estimated at 1.96 times the standard deviation, the PRL measurement program is capable of detecting changes to the sound power emissions of a specific device on the order of 0.5 dB and to determine the true value of the sound power emissions with an uncertainty of about 4 dBA.

A Bruel and Kjaer pulse system served as the data-acquisition system for the sound power-level determinations associated with this research. One-third octave band sound pressure levels are collected by the pulse system at 15 microphone locations within the reverberation chamber and these data are dynamically linked to an Excel spreadsheet in real time. In Excel, these data are logarithmically averaged to calculate an average sound pressure level for the test. These measurements are conducted for a calibrated reference sound source and then on the device under test. These sound pressure-level data are then used to calculate the sound power-level emissions for the device using the comparison method with the equation

$$L_W = L_{Wr} + (L_p - L_{pr}) \quad (1)$$

where

L_W is the sound power of the device under test,

L_{Wr} is the sound power of a calibrated reference sound source,

L_p is the averaged sound pressure level of the device under test and

L_{pr} is the averaged sound pressure level for the calibrated reference sound source.

The sound power level is calculated for each one-third-octave band, and these values are logarithmically summed to calculate an overall sound power level.

Because roof bolter testing requires a rather large drill media (granite), as well as a large support stand, NIOSH constructed a steel support apparatus to hold the drilling media (Fig. 2). Care was taken to ensure that the stand did not radiate significant amounts of sound energy. To prevent this, the support stand, with the exception of its diagonal members and the short horizontal members along its minimum direction of the top of the structure, are filled with sand, and two layers of urethane are bonded to the rock support members below the drill media. Finally, an additional layer of urethane is laid between the drill media and chain holding the rock in place. All of these measures serve to reduce vibration transmissions into the stand and noise emissions from the stand surfaces. The device was placed near one corner of the chamber in accordance with the spacing requirements listed in ISO 3743-2.

Typically, testing of this type in conducted without anyone in the test chamber. However, because the roof bolter cannot be operated remotely, an operator was allowed in the reverberation chamber during testing. The high noise level in the chamber necessitated the operator wear double hearing protection, consisting of earplugs and earmuffs.

In formulating a conservative test plan, it was decided to use drilling components and parameters that were representative of industry usage. These are listed in Table 2. Various combinations of these comprise the test configurations. Drill media of three compressive-strength ranges were tested: a low compressive strength material (concrete), an intermediate compressive strength material (sandstone) and a high compressive strength material (granite). These providing for a wide range of penetration rates with respect to noise emissions (Table 3).

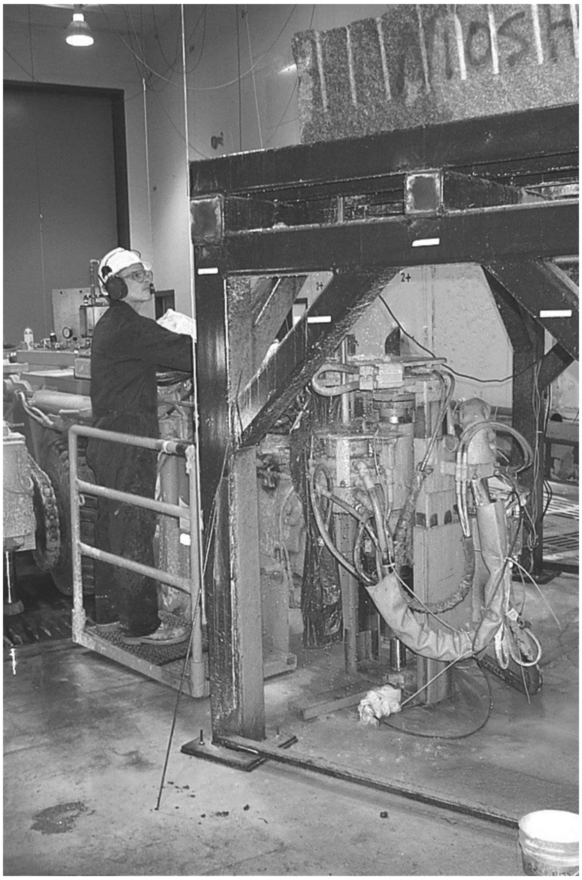

Figure 2 — Drilling support fixture loaded with granite.

Table 2 — Sound power level testing variables.

Item	Values
Drilling type	vacuum, mist at 3 qt/min, wet at 3 gpm*
Drill steel	round, hexagonal
Drill bit size	1 and 1 3/8 in. (25.4 and 34.9 mm)
Rotation speed, rpm	200, 300, 300, 400, 500, 600
Thrust, lbs	2,121, 2,828, 3,535, 4,242, 4,949, 5,656** and 6,363**

*This report limited to vacuum and wet drilling.
**34.9-mm (1 3/8-in.) bit size only.

Table 3 — Drill media compressive strengths.

Drill media	Compressive strength, lbs
Concrete	6,000
Sandstone	16,000 to 21,000
Granite*	24,000

*This report limited to granite data.

Granite test results

The data listed in the following discussion are the average sound power levels (L_{wA}) expressed in A-weighted decibels (dBA) and the penetration rates (in./sec) of two tests at a given test configuration. The sound power levels of these two tests varied by not more than 1.0 dBA. Further, all like tests (e.g., same steel shape and bit size) are averaged for a given thrust or rotation speed. This facilitates illustrating trends showing the affects of thrusts or rotation speeds on the data.

Round drill steel compared to hexagonal drill steel. For vacuum tests and relative to thrust, the 25.4 mm (1-in.) round drill steel results generates a lower sound power than similar hex drill steel tests. The reverse is true for wet test results, though the differences are negligible (Fig. 3). While an increased thrust does yield an increased sound power level, the differences, again, are negligible.

As was the case with thrust, when using rotation speed as a comparative basis, the vacuum round drill steel results indicate a lower sound power than similar hex drill steel tests. For wet testing, there is no difference between the 25.4 mm (1-in.) and the 34.9-mm (1 3/8-in.) round and hex results. At lower rotation speeds, the 25.4-mm (1-in.) hex results showed

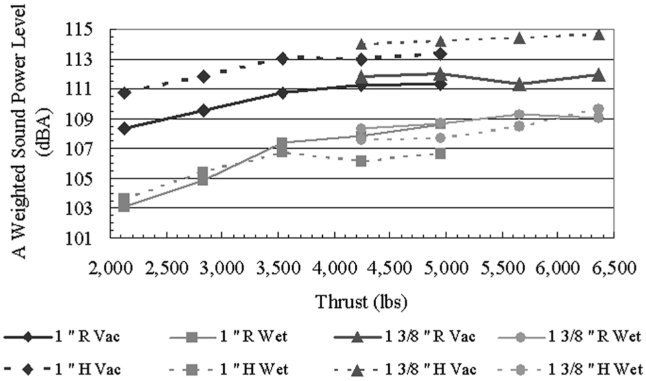

Figure 3 — Round (solid) and hex (dash) L_{wA} vs. thrust.

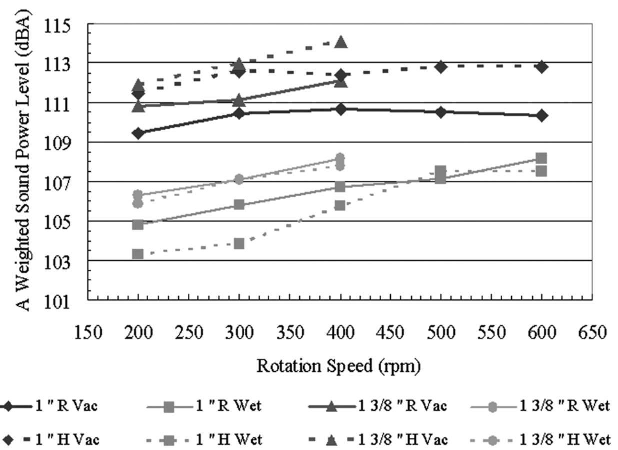

Figure 4 — Round (solid) and hex (dash) L_{wA} vs. rotation speed.

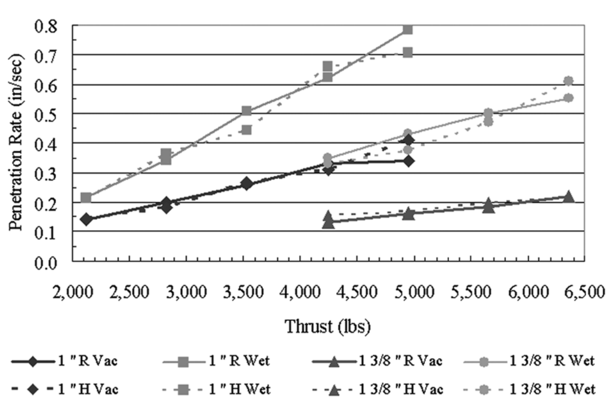

Figure 5 — Round (solid) and hex (dash) penetration rate vs. thrust.

sound power levels less than the 25.4-mm (1-in.) round, but the advantage disappears at 500 and 600 rpm (Fig. 4). There was also the unexpected result where the sound power level decreased with increasing rotation speed for the 25.4-mm (1-in.) vacuum tests.

As for performance, the penetration rate did not vary significantly when comparing round and hex data, whether using thrust

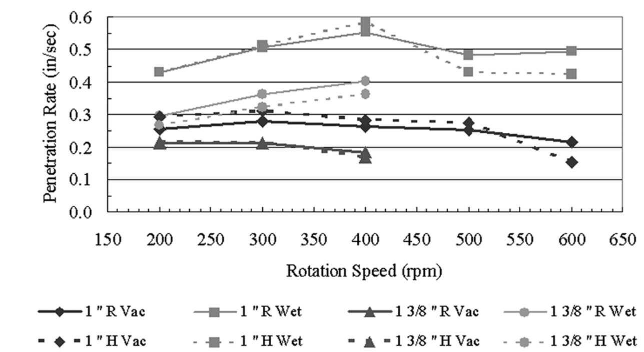

Figure 6 — Round (solid) and hex (dash) penetration rate vs. rotation speed.

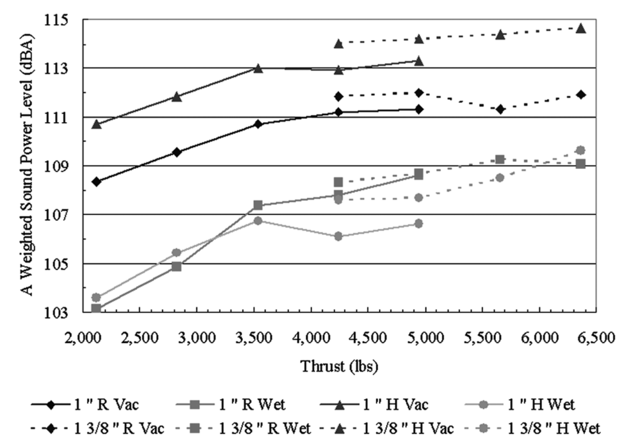

Figure 7 — 25.4 mm (1 in.) (solid) vs. 3.49 mm (1 3/8 in.) (dash) L_{wA} vs. thrust.

or rotation speed as a comparative basis (Figs. 5 and 6).

Recommendations: When drilling into hard materials having high compressive strengths, for vacuum drilling use round drill steels and use hex drill steels for wet drilling. While increasing thrust or rotation speed increases sound power emission, the affects are minimal. For performance, there appeared to be little difference between the round and hex drill steels.

25.4-mm (1-in.) diameter compared to 34.9-mm (1 3/8-in.) diameter. To date, there is little overlap for thrust data when comparing 25.4-mm (1-in.) and 34.9 mm (1 3/8-in.) data, but what can be seen is that there is a 1 to 2 dBA difference between the larger drill bits and the smaller drill bits, with the 25.4 mm (1-in.) being slightly quieter (Fig. 7).

Relative to rotation speed, the 34.9-mm (1 3/8-in.) L_{wA} results were slightly higher than similar results for 25.4-mm (1-in.) tests. These varied by up to 2.5 dBA (Fig. 8).

Analysis showed that thrust has a significant affect on the penetration rate for all cases (Fig. 9). The 25.4-mm (1-in.) performance was on the order of two to three times that of the 34.9-mm (1 3/8-in.) data, a significant difference.

Similar results are observed when comparing the data on a rotation speed basis. The 25.4-mm (1-in.) drill performed significantly better than the 34.9-mm (1 3/8-in.) drill (Fig. 10).

Recommendations: When drilling into hard materials having high compressive strengths, 25.4-mm (1-in.) drill bits are

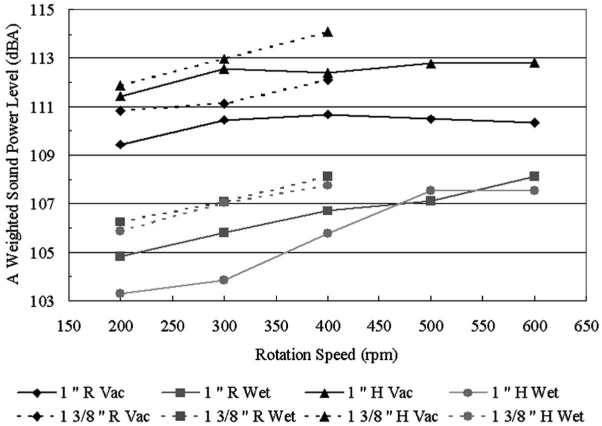

Figure 8 — 25.4 mm (1 in.) (solid) vs. 3.49 mm (1 3/8 in.) (dash) L_{wA} rotation speed.

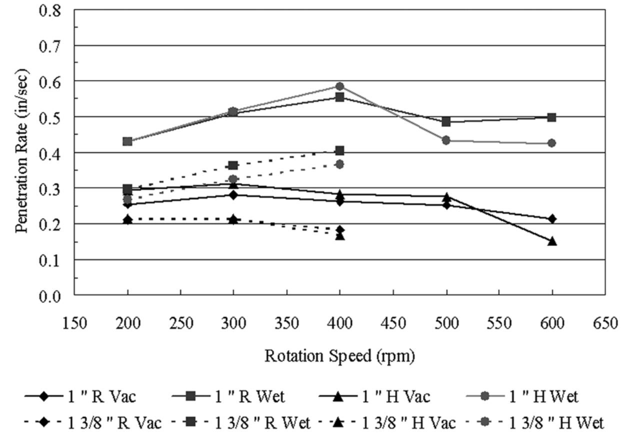

Figure 10 — 25.4 mm (1 in.) (solid) vs. 3.49 mm (1 3/8 in.) (dash) penetration rate vs. rotation speed.

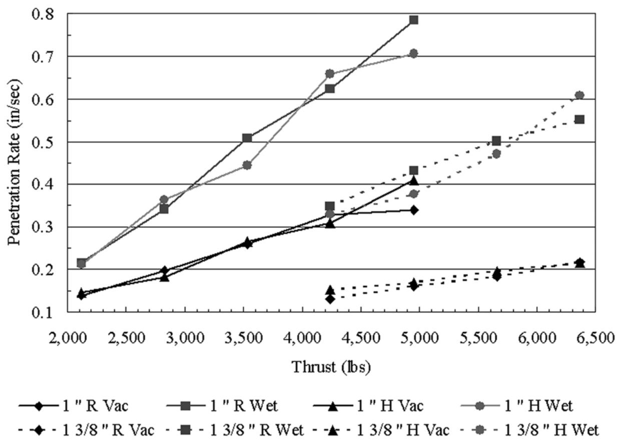

Figure 9 — 25.4 mm (1 in.) (solid) vs. 3.49 mm (1 3/8 in.) (dash) penetration rate vs. thrust.

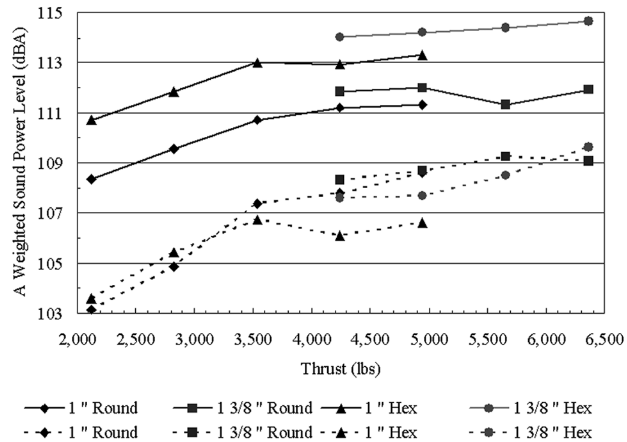

Figure 11 — Vacuum (solid) and wet (dash) L_{wA} vs. thrust.

slightly quieter than the 34.9-mm (1 3/8-in.) drill bits. It was shown that 25.4 mm (1-in.) bits drill significantly faster than 34.9-mm (1 3/8-in.) bits. Increasing thrust will improve performance. As for rotation speed, lower values tend to perform better. It is advised to try lowering rotation speeds to the 200 to 400 rpm range and then evaluate its affect on performance and noise exposure.

Vacuum drilling compared to wet drilling. Wet drilling proved to emit less noise than similar tests conducted under vacuum conditions. Figures 11 and 12 show vacuum and wet drilling tests A-weighted sound power levels plotted vs. thrust and speed, and in all comparative cases, the wet drilling produced sound power levels lower than vacuum drilling. The differences between the sound power levels for vacuum and wet drilling are shown in Figs. 13 and 14.

Much of this difference is attributable to the lubricating affect of the water, which attenuates higher frequency noise. An example of this effect is given in Fig. 15. Here, 25.4-mm (1-in.) round data tested at a thrust of 2,245 kg (4,949 lbs) and a rotation speed of 200 rpm are given for testing under both vacuum and wet conditions. For all one-third octave band frequencies of 1,000 Hz and greater, it is clearly shown that the sound power levels are greater for vacuum drilling. Four

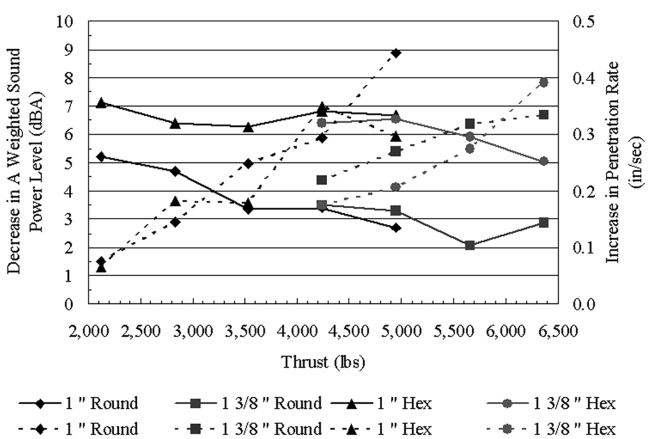

Figure 12 — Vacuum (solid) and wet (dash) L_{wA} vs. rotation speed.

examples of this are listed in Table 4. For each case, the sound power level contributions for the one-third octave bands from 50 through 800 Hz are essentially the same for vacuum and wet drilling, e.g., for the 25.4 mm (1-in.) round case they are 95 and 96 dBA, respectively. There is a significantly larger

Table 4 — Sound power level contributions of two frequency bands.

Size and shape	Thrust, lbs Speed, rpm	Frequency band, Hz	Vacuum L_{wA}	Wet L_{wA}
1 in. round	4,949	50 through 800	95	96
	400	1 k through 10 k	113	108
1 3/8 in. round	6,363	50 through 800	96	96
	400	1 k through 10 k	115	109
1 in. hex	4,949	50 through 800	93	96
	400	1 k through 10 k	112	105
1 3/8 in. hex	5,656	50 through 800	97	95
	200	1 k through 10 k	114	107

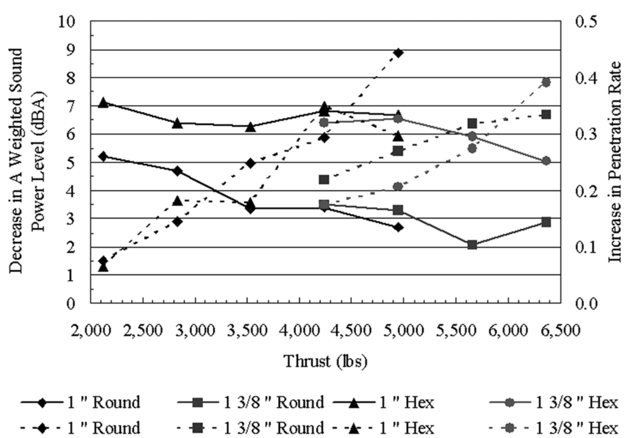

Figure 13 — Changes in L_{wA} (solid) and penetration rate (dash), vacuum to wet drilling.

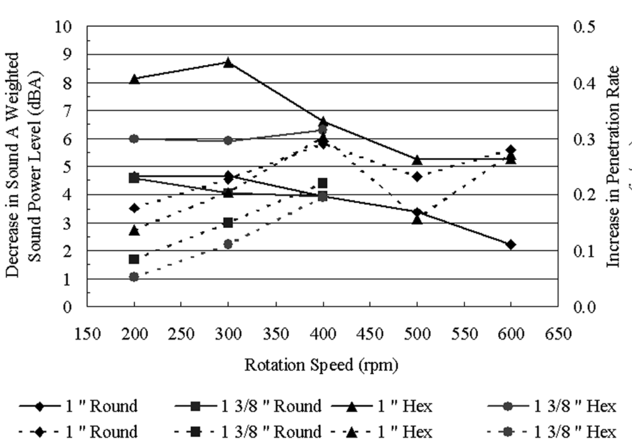

Figure 14 — Changes in L_{wA} (solid) and penetration rate (dash), vacuum to wet drilling.

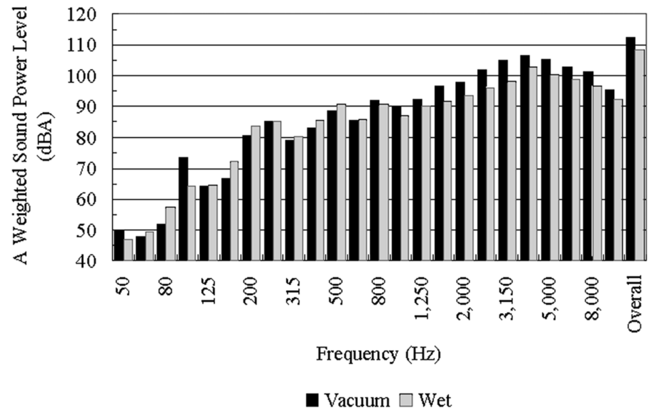

Figure 15 — Round 1-in. (25.4-mm) vacuum and wet L_{wA}, 2,245 kg (4,949 lbs) thrust, 200 rpm.

difference in the frequency range 1 through 10 kHz. For the 25.4 mm (1-in.) round example, there is a 5-dBA difference. Similar results are listed for the other three cases.

Further analysis indicated another key point. The overall A-weighted sound power levels are essentially unaffected by the sound power generated in the one-third octave bands below 1 kHz. For each example given, the overall A-weighted sound power level is the same as the 1 through 10 kHz contributions, given rounding the sound power levels to the nearest dBA.

As for performance, i.e., the penetration rate, vacuum drilling did not perform as well as the wet drilling (Figs. 16 and 17). For each comparative case, the wet drilling penetration rate exceeded the vacuum drilling penetration rate, on occasion significantly. Referring back to Figs. 14 and 15, the increase in the penetration rate vacuum to wet drilling is given.

As mentioned above, increasing thrust tends to slowly increase the sound power level emission (Figs. 11 and 12), while the same cannot be said for increasing rotation speed. As evident in Figs. 16 and 17, increasing the rotation speed increases the sound power level emission but begins to negatively affect the drilling performance.

Recommendations: When drilling into hard materials having high compressive strengths, use wet drilling as opposed to vacuum, if possible, to decrease sound power level emissions and increase performance. Further, investigate lowering rotation speed to 200 to 400 rpm and then evaluate its affect on performance and noise exposure.

Conclusions

Drilling with water has a significant influence on lowering the sound power emissions of the roof bolter tested by NIOSH when compared to vacuum drilling. The primary affect is in attenuating noise at the frequencies above 1 kHz, which are the dominant contributors to the overall sound power level emissions. Thus, where conditions permit, it would be advantageous to explore wet drilling. For vacuum drilling, round drill steel testing resulted in slightly lower sound power emissions than hex drill steels, while the reverse was true for wet drilling.

In general, experimental results show that drilling performance increased as the thrust increased, while higher rotation speeds yielded diminishing results. It is suggested that when drilling into hard materials, lower rotation speeds should be attempted and their affects on performance should then be evaluated. Additionally, water increased the performance of the drilling as well. In terms of drilling performance, there appeared to be little difference between round and hex drill steels and 25.4 mm (1-in.) bits performed significantly better than 34.9-mm (1 3/8-in.) bits.

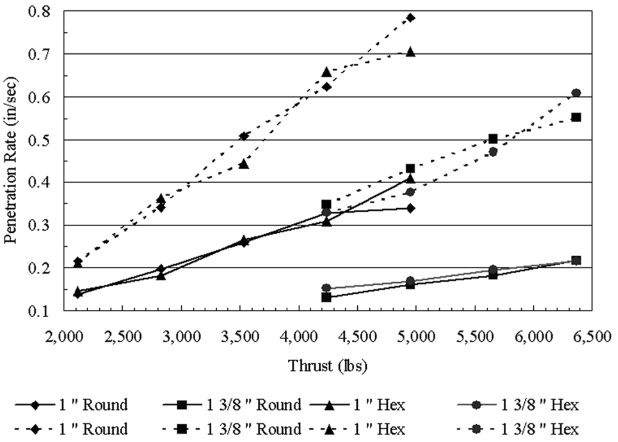

Figure 16 — Vacuum (solid) and wet (dash) penetration rate vs. thrust.

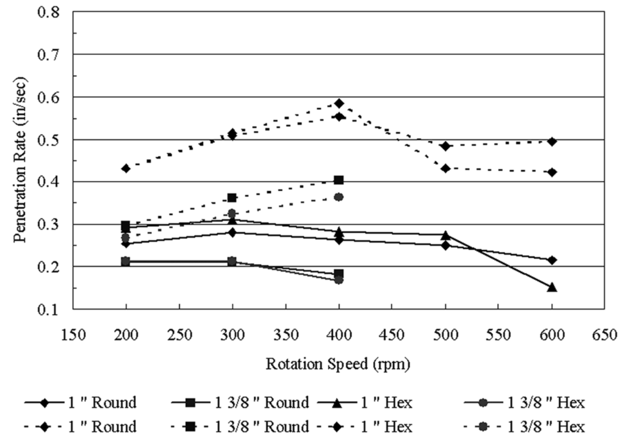

Figure 17 — Vacuum (solid) and wet (dash) penetration rate vs. rotation speed.

Future work

Future testing will entail completing mist system experiments for all three rock media and wet and vacuum testing in sandstone.

Additional tests will also be conducted to fill in gaps in the data.

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