Acoustic assessment of pneumatic and electric jackleg drills used in the mining industry

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Hearing loss is the most prevalent disease among miners. A study of U.S. western hard-rock mines revealed that 96% of machine operators were overexposed to noise, with jackleg drill operators having the most rapid noise dose accumulation. Traditionally, jackleg drills have been driven by pneumatic power. However, there are currently available rotary hammer drills powered by electricity. This paper presents an acoustic assessment of pneumatic and electric jackleg drills that involved Noise Source Identification (NSID), penetration rate measurements, operator's cumulative noise dose measurements, and the determination of sound power levels. NSID using beamforming array technology revealed two dominant noise sources for the electric drill, one located at the drill and one located at the drill steel-rock interaction place. In contrast, NSID for the pneumatic drill showed only one dominant noise source located at the drill. Penetration rate and noise dose measurements were combined to estimate the accumulated dose and time required to drill a reference depth hole. Sound power level measurements while drilling into granite yielded overall levels of 115.3 dB(A) and 123.4 dB(A) for the electric and pneumatic drills, respectively. The results show that from an occupational noise exposure perspective the acoustic performance of the electric drill, despite its slower penetration rates, overcomes the benefits of traditional pneumatic drills.

1 INTRODUCTION

Occupational hearing loss is still the most prevalent disease in the mining industry. A study of U.S. western hard-rock miner's noise exposure revealed that 96% of hard-rock mining machine operators were exposed to levels exceeding the Permissible Exposure Level (PEL) set

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by the Mine Safety and Health Administration (MSHA)[1]. Time-motion analysis further showed that for all mining machine operators, jackleg drill operators had the most rapid noise dose accumulation.

Jackleg drills, simply referred to as “drills” throughout this paper, are used to drill blast holes as well as bolt holes, especially in narrow vein situations. Traditionally, these drills have been driven by pneumatic power. However, there are currently available rotary hammer drills powered by electricity. These electric drills are less noisy and have lower vibration levels than pneumatic drills and constitute an attractive alternative to pneumatic drills; nevertheless, electric drills also have lower penetration rates as compared to pneumatic drills[2]. As a consequence, the acoustic and vibration benefits of the electric drills tend to be overshadowed by the slower penetration rates.

Previous studies conducted by the United States Bureau of Mines identified three dominant noise sources: the exhaust, drill machinery noise, and drill steel noise[3]. The noise at the exhaust is produced by the turbulence of the discharge air and thus it is of aeroacoustic type. The drill machinery noise arises from the fluctuating air flow inside the drill, and also from the impacts among internal components of the drill. Drill steel noise is originated by the vibration of the drill steel rod.

This paper presents the results of a series of tests conducted by the Office of Mine Safety and Health Research (OMSHR) to assess the acoustic performance of both pneumatic drills and electric drills used in the mining industry. The objective of this assessment is to determine, from an occupational noise exposure perspective, whether electric drills constitute a viable alternative to pneumatic drills.

2 EXPERIMENTAL SETUP

Two rock drills were used for the present study. A Gardner Denver model S83 pneumatic drill and a Hilti model TE MD20 rotary hammer electric drill. Furthermore, the pneumatic drill was provided with a muffler and therefore measurements for this drill were conducted with and without the muffler. Figure 1 shows the pneumatic drill with and without muffler as well as the electric drill. The characteristics of the drill steel and drill bit of the rock drill under test are presented in Table 1. For all tests, two different drill media were used: granite with a compressive strength of 138 MPa (20000 psi), and concrete with a compressive strength of 41.3 MPa (6000 psi). For consistency purposes, each hole was collared, i.e. started to a depth of 0.6 cm (0.25 inch), before collecting data.

The study consisted of sound pressure level measurements, phased array measurements, dosimeter measurements, and penetration rate measurements in a hemi-anechoic chamber. Furthermore, the study included the determination of sound power levels which were conducted in a reverberation chamber accredited by the National Voluntary Laboratory Accreditation Program (NVLAP). All the above measurements were conducted in the facilities of the Office of Mine Safety and Health Research in Pittsburgh.

The beamforming array used for noise source identification purposes consisted of 42 microphones distributed on a wheel-type configuration with a 1.98-m diameter. The array plane was located 3.7 meters (145.7 inches) away from a plane containing the drill steel. Figure 2 shows the phased array, the drill media, and one of the drills under test in the hemi-anechoic chamber.

3 SOUND PRESSURE LEVEL MEASUREMENTS

Sound pressure level measurements were conducted in order to assess the acoustic field of the sound radiated by the drills during operation. To this end, single microphone measurements were conducted in the hemi-anechoic chamber at the following three locations: 1) At the operator's location, 2) at 3.0 meters (10 feet) away from the operator's location, and 3) at 6.1 meters (20 feet) away from the operator's location, as shown in Fig. 2. The results from these tests are shown in Fig. 3. From the plots in this figure, it can be seen that the acoustic field of the pneumatic drills have flatter spectra as compared to the spectra of the electric drill. Furthermore, it can be seen that the spectra of the electric drill have significant contribution in the 1600 Hz to 10000 Hz frequency range. Below 1600 Hz, the sound pressure levels of the electric drill are significantly lower than the levels of the pneumatic drill with differences ranging between 10 dB(A) to 30 dB(A). Figure 3 also show that the effect of the muffler on the pneumatic drills is more significant in the 1000 Hz to 2000 Hz frequency range with differences ranging between 3 dB(A) and 10 dB(A).

4 NOISE SOURCE IDENTIFICATION

Noise source identification involves the determination of the physical location as well as the frequency content of the dominant noise sources. To accomplish these tasks, a microphone array was used to sample the acoustic field. The data were then processed using a conventional beamforming algorithm to determine the location of the dominant noise sources. The processing plane was selected to be the plane containing the drill steel. The results from this processing were obtained in the form of one-third octave band acoustic maps. These maps have a dynamic range of approximately 13 dB at 1000 Hz. As the frequency increases, the dynamic range of the acoustic maps decreases to approximately 9.5 dB at 5000 Hz.

Figure 4 presents the acoustic maps in the 1600 Hz to 4000 Hz frequency range for the two configurations of the pneumatic drill (S83 and the S83 with muffler), and the electric drill (TE MD20). From these maps it can be observed that for the case of the S83 drill, i.e. maps on the left column, there is only one dominant noise source which is located at the drill body. The center column of Fig. 4 shows the acoustic maps when a muffler was installed on the S83 drill. From these maps, it can be seen that the levels in the 1600 Hz to 2500 Hz frequency range were reduced significantly, i.e. up to 10 dB, and now, since the dynamic range has been lowered, there are two dominant noise sources: one source is located at the place where the drill bit interacts with the rock, and the other source is located at the drill body. Furthermore, at higher frequencies, i.e. 3150 Hz and 4000 Hz, there is only one dominant source located at the drill bit-rock interaction place. Therefore, the effect of the muffler is to reduce the source at the drill, i.e. exhaust noise, to a level that is comparable to the noise source at the drill bit-rock interaction place.

The third column of Fig. 4 shows the acoustic maps of the electric drill. From these maps it can be seen that with the exception of the 1600 Hz map, there is only one dominant noise source located at the drill bit-rock interaction place. Comparison of the levels of the electric drill with the levels of the pneumatic drill with muffler reveals a further reduction in noise, i.e. between 2 dB and 9 dB.

5 NOISE DOSE ACCUMULATION

Another variable that was measured during the present study is the noise dose accumulated by the operator of the drill. The cumulative dose of the operator of any mining machine during any work shift is what eventually determines whether or not the operator complies with the Title 30 of the Code of Federal Regulations Part 62[4].

To assess the accumulated dose, a Spark 705+ dosimeter was placed at the operator's shoulder, close to the ear. The dosimeter was set up per the Mine Safety and Health Administration (MSHA) Permissible Exposure Level (PEL): 90 dB criterion and threshold level and a 5 dB exchange rate.

Figure 5 shows the cumulative dose as a function of time while drilling concrete in the hemi-anechoic chamber. In this figure, the three segments corresponding to the dose accumulated while operating each tested drill are clearly identified. From this figure, it can be seen that the operator accumulates dose more rapidly while operating the S83 drill. These results were used to estimate average cumulative dose rates per minute which are summarized in Table 2. This table also shows the time required to reach 100% dose.

6 PENETRATION RATE

The penetration rate of every drilled hole was determined by dividing the hole depth by the time required to drill that particular hole. Figure 6 shows the average penetration rates of the pneumatic and electric drills in granite and in concrete. From this figure it can be seen that the penetration rate of the electric drill is approximately 61% and 66% the penetration rate of the pneumatic drill in concrete and granite, respectively. Using these penetration rates, and the time required to reach 100% dose, presented in Table2, allows estimating the number of 1.2 meter (48-inch) depth reference holes the operator can drill before accumulating 100% dose. As a result, as shown in Table 3, the operator of the pneumatic drill provided with a muffler would drill 36 holes in concrete, while the operator of the electric drill would drill 54 holes in the same media. The difference is even larger when drilling in granite where the operator of the pneumatic drill would complete 12 holes as compared to 24 holes when using the electric drill. Regarding the time required to drill a reference 1.2 meter (48 inch) hole in concrete, it would take 1.98 minutes using the S83 with muffler as opposed to 3.24 minutes using the TE MD20. Similarly, it would take 3.22 minutes to complete a 1.2 meter (48-inch) reference hole in granite using the S83 with muffler, while it would require 4.89 minutes to drill the same hole using the TE MD20 drill. During this time, the operator of the pneumatic drill with muffler would accumulate approximately 8.1% dose, while the operator of the electric drill would accumulate 4.2% dose.

7 DETERMINATION OF SOUND POWER LEVELS

The last test of this study consisted in the determination of the sound power level radiated by each drill in a reverberation chamber. The sound power of a noise source measures the actual sound energy emission of a device and does not vary with the surrounding environment, as it is the case with sound pressure. Thus, it is a valuable tool for comparing the noise generated by the drills under test. The sound radiated by every drill was sampled three times for 30 seconds each. The pneumatic drill was tested with and without the muffler installed. Figure 7 shows the one-third-octave band plots of the sound power levels for the drills. From Fig. 7a it can be seen that the sound power level while drilling into concrete for the electric drill was 10.5 dB(A) and 7.2 dB(A) lower that the sound power radiated by the pneumatic drill without, and with muffler, respectively. Similarly, Fig. 7b shows that drilling into granite resulted in differences of 8.1 dB(A) and 4.8 dB(A) between the pneumatic drill and the electric drill, and between the pneumatic drill with muffler and the electric drill, respectively

8 CONCLUSIONS

An assessment of the acoustic performance of a pneumatic drill and an electric drill was conducted. Microphone array measurements processed with a beamforming algorithm showed that for the case of the pneumatic drill, there is only one dominant source located at the drill body. Installing a muffler reduces the levels of this source in the 500 Hz to 2500 Hz by up to 10 dB. As a consequence, the acoustic maps of the pneumatic drill with silencer show two dominant sources located at the drill body and at the drill bit-rock interaction place. However, the presence of these two noise sources is due to the fact that the dynamic range was lowered and not due to operational changes. For the case of the electric drill, the acoustic maps show that, with the exception of the 1600 Hz band, there is only one dominant source located at the drill bit-rock interaction place.

Penetration rate measurements showed that the electric drill has approximately 61% and 66% the penetration rate of the pneumatic drill in concrete and granite, respectively. On the other hand, dosimeter measurements showed that the operator of the electric drill would accumulate noise dose at a rate 40% and 34% the rate of the pneumatic drill operator in concrete and granite respectively. Thus, to drill a 1.2 meter (48 inch) depth reference hole in granite, it would take 3.22 minutes using the S83 with muffler as opposed to 4.89 minutes using the TE MD20. During this time, the operator of the pneumatic drill with muffler would accumulate approximately 8.1% dose, while the operator of the electric drill would accumulate 4.2% dose.

Sound power level measurements in granite revealed a difference of 8.1 dB(A) and 4.8 dB(A) between the pneumatic drill and the electric drill, and between the pneumatic drill with muffler and the electric drill, respectively. Similarly, drilling into concrete resulted in differences of 10.5 dB(A) and 7.2 dB(A) between the pneumatic drill and the electric drill, and between the pneumatic drill with muffler and the electric drill, respectively. In conclusion, from an occupational noise exposure perspective, the acoustic performance of the electric drill, despite its slower penetration rates, overcomes the benefits of traditional pneumatic drills.

9. ACKNOWLEDGMENTS

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10 REFERENCES

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2. J.I. Phillips, P.S. Heyns and G. Nelson, G., "Rock Drills used in South African Mines: a Comparative Study of Noise and Vibration Levels", *The Annals of Occupational Hygiene*, **51**(3), 305-310, (2007).

3. A. Visnapuu and J. Jensen, J., "Noise Reduction of a Pneumatic Rock Drill", United States Bureau of Mines Report of Investigation, RI8082, (1975).

4. Title 30 CFR Part 62, U.S. Department of Labor, Mine Safety and Health Administration, Information Resource Center, (2000-2005)

Table 1 - Drill steel and drill bit specifications for the drills under test.

Part	Gardner Denver S83	Hilti TE MD20
Drill Steel:		
Length m (in)	1.524 (60)	1.524 (60)
Diameter m (in)	0.0254 (1)	0.0222 (7/8)
Cross Section	Hexagonal	Hexagonal
Drill Bit:		
Type	B&L POK Bit	8-Butt Bit
Diameter	0.0349 (1 3/8)	0.0349 (1 3/8)

Table 2 - Operator cumulative noise dose.

Brand	Model	Configuration	Concrete		Granite	
			Accumulated Dose (%/min)	Time to Reach 100 % Dose (min)	Accumulated Dose (%/min)	Time to Reach 100 % Dose (min)
Gardner Denver	S83	Standard	4.63	21.58	5.38	18.58
Gardner Denver	S83	With Muffler	1.41	70.92	2.50	39.97
Hilti	TE 20MD	Standard	0.57	174.48	0.85	118.13

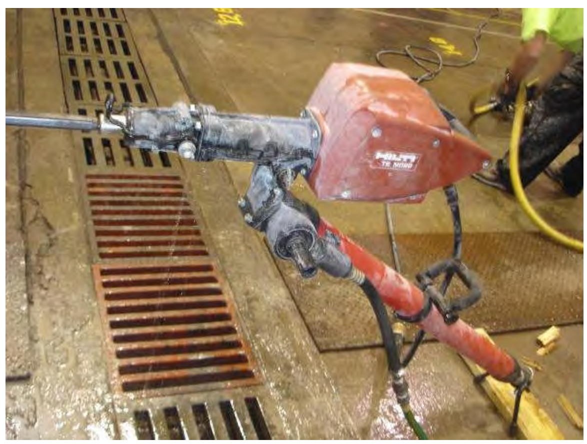
Table 3 - Penetration rate and maximum number of holes before reaching 100% dose.

Brand	Model	Configuration	Concrete		Granite	
			Penetration Rate (in/min)	Number of holes before reaching 100 % Dose (*)	Penetration Rate (in/min)	Number of holes before reaching 100% Dose (*)
Gardner Denver	S83	Standard	23.5	10.6	12.8	5.0
Gardner Denver	S83	With Muffler	24.3	35.9	14.9	12.4
Hilti	TE 20MD	Standard	14.8	53.8	9.9	24.3

(*) For reference purposes, 48-in depth holes were used for this calculation.

(a) Gardner Denver S83.

(b) Gardner Denver S83 with muffler.



(c) Hilti TE MD20.

Fig. 1 - Drills under test.

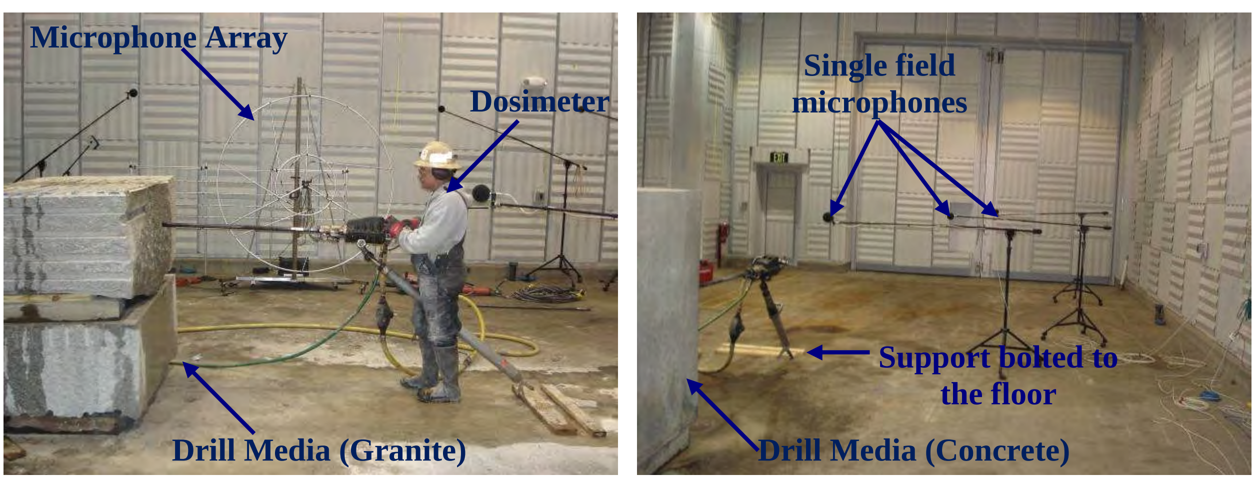
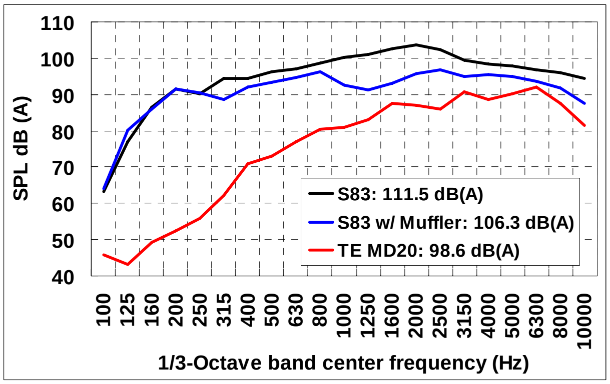
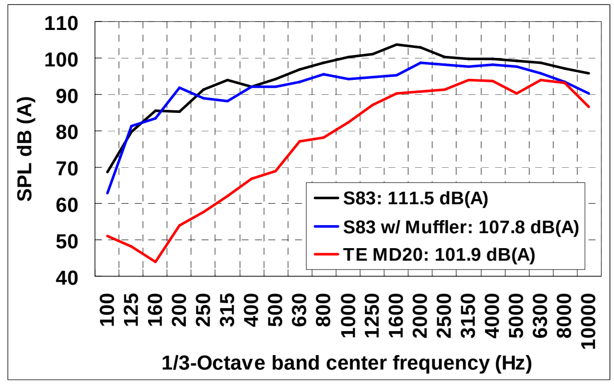


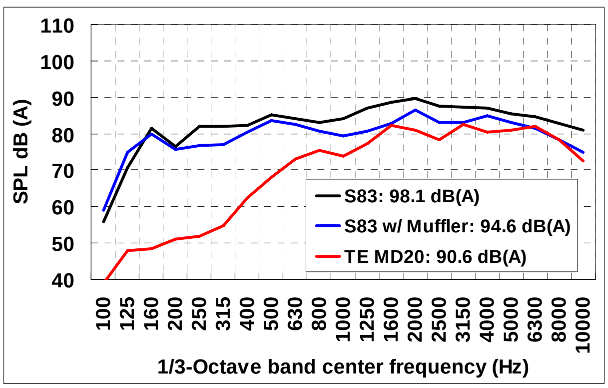
Fig. 2 - Experimental setup in the hemi-anechoic chamber for noise source identification, dose accumulation and single field microphone measurements.



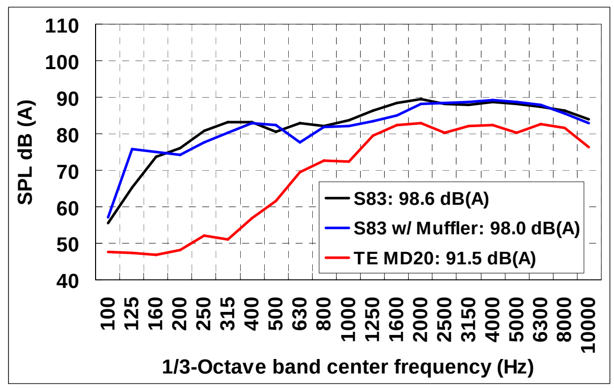
(a) At operator's location (Concrete).



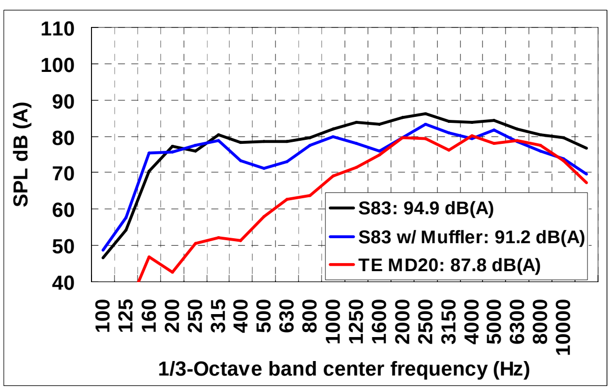
(b) At operator's location (Granite).



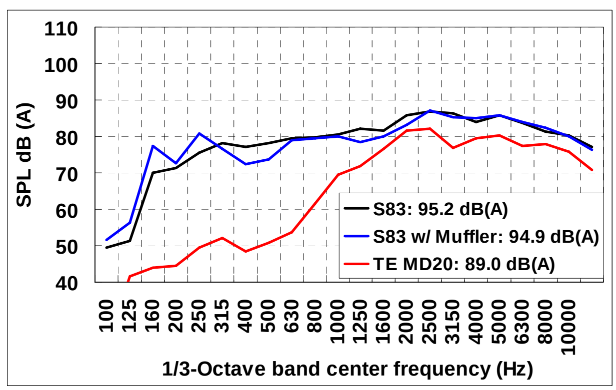
(c) At 3.048-m from the operator (Concrete).



(d) At 3.048-m from the operator (Granite).



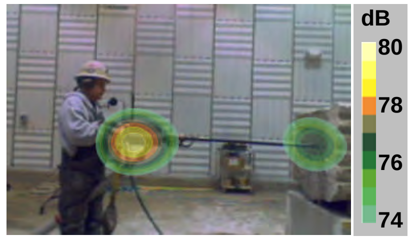
(e) At 6.096-m from the operator (Concrete).



(f) At 6.096-m from the operator (Granite).

Fig. 3 - SPL during the drilling operation at three different locations.

(a) S83 at 1600 Hz.



(b) S83 w/muffler at 1600 Hz.

(c) TE MD20 at 1600 Hz.

(d) S83 at 2000 Hz.

(e) S83 w/muffler at 2000 Hz.

(f) TE MD20 at 2000 Hz.

(g) S83 at 2500 Hz.

(h) S83 w/muffler at 2500 Hz.

(i) TE MD20 at 2500 Hz.

(j) S83 at 3150 Hz.

(k) S83 w/muffler at 3150 Hz.

(l) TE MD20 at 3150 Hz.

(m) S83 at 4000 Hz.

(n) S83 w/muffler at 4000 Hz.

(o) TE MD20 at 4000 Hz.

Fig. 4 - One-third octave band acoustic maps for two pneumatic drills (S83 and S83 with muffler), and an electric drill (TE MD20).

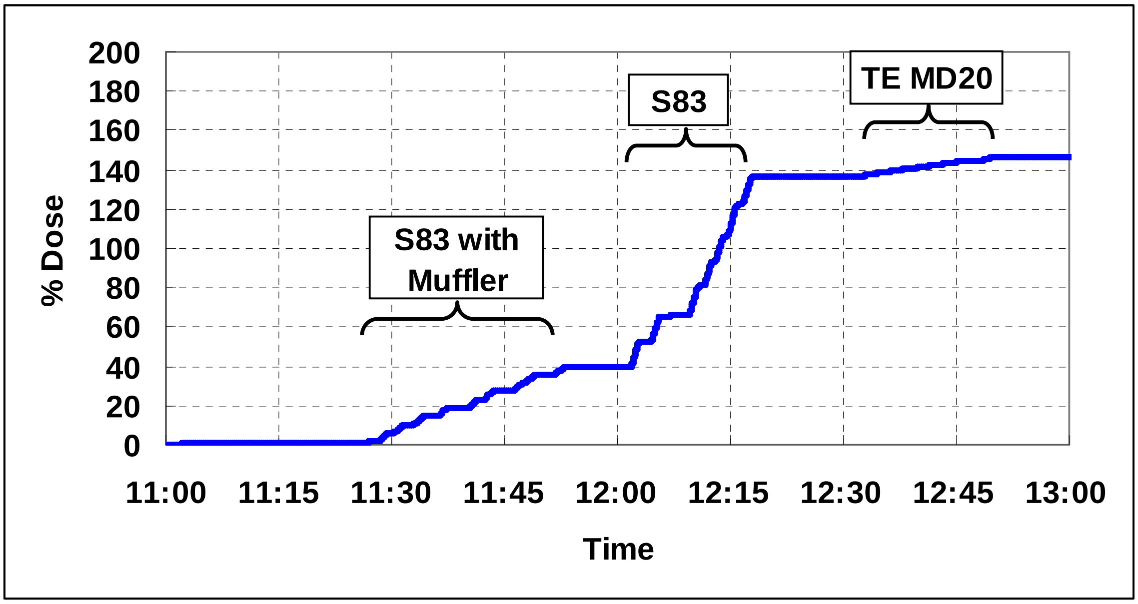


Fig. 5 - Cumulative dose for the three tested drills while drilling in concrete.

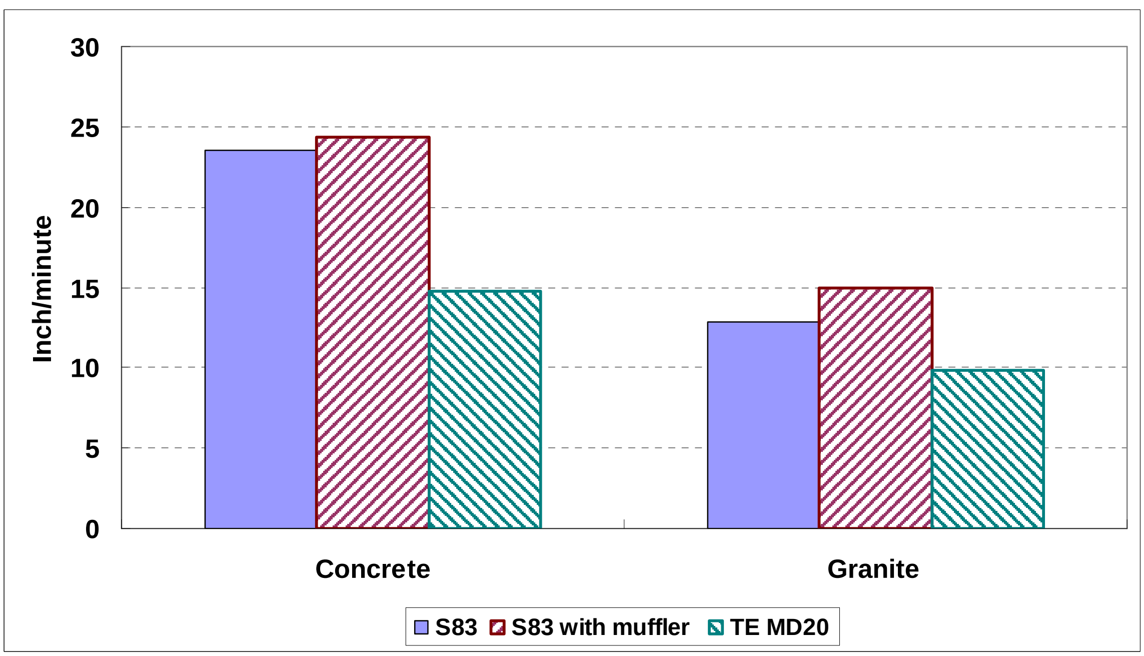
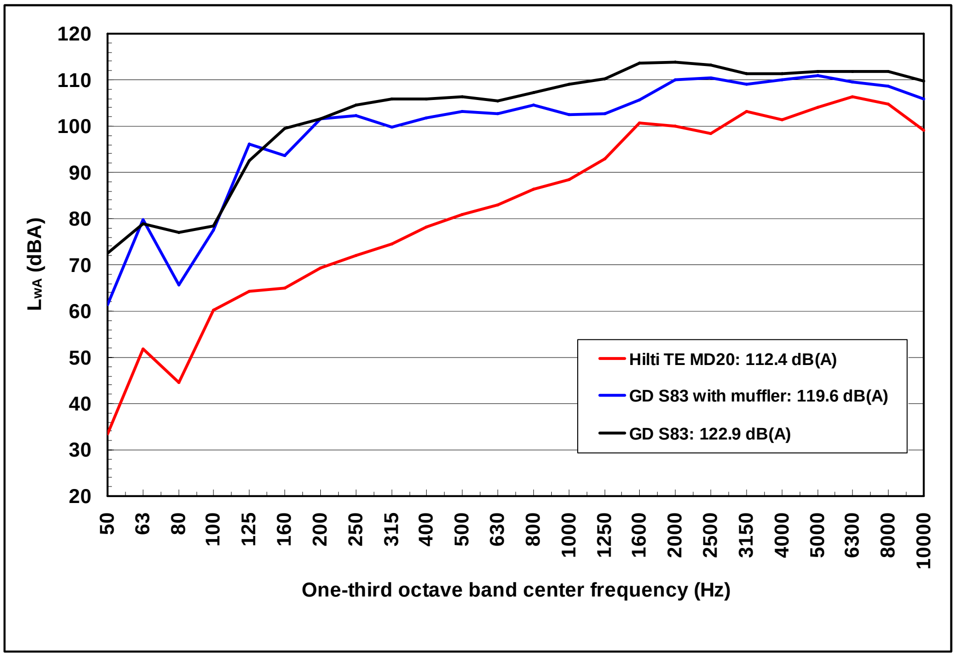
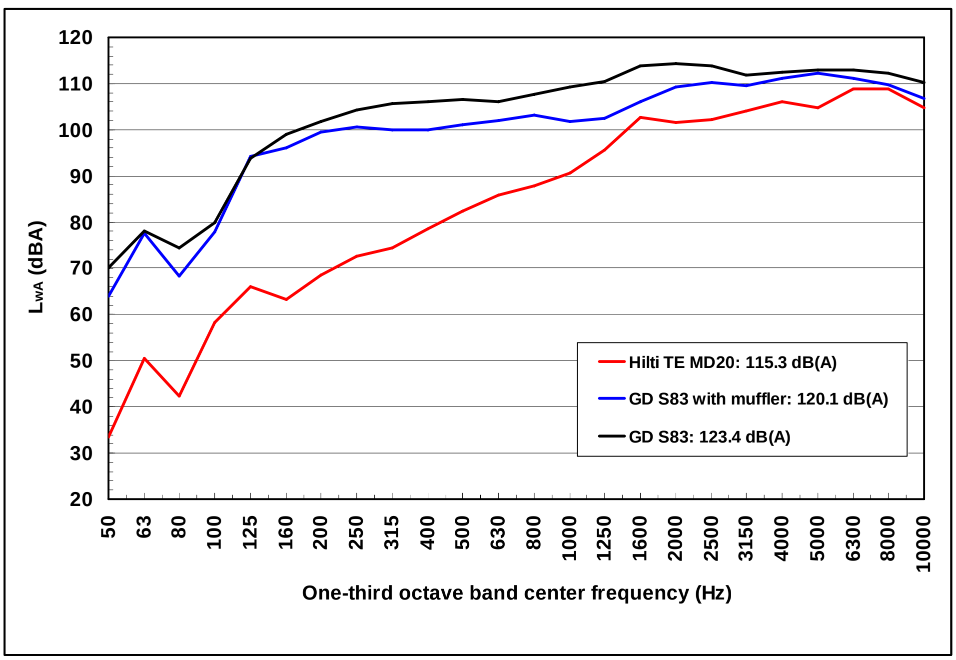


Fig. 6 - Penetration rate.



(a) Concrete.



(b) Granite.

Fig. 7 - Sound Power Level radiated by the drills.