The development of a damped drill steel to reduce roof bolting machine drilling noise[1)]

J. Shawn Peterson[a)]
Hugo Camargo[b)]
NIOSH
Office of Mine Safety and Health Research
626 Cochrans Mill Road
Pittsburgh, Pennsylvania 15236

Among underground coal miners, hearing loss remains one of the most common occupational illnesses. In response, the National Institute for Occupational Safety and Health (NIOSH) conducts research to reduce the noise emission of underground coal mining equipment, an example of which is a roof bolting machine. Field studies support the premise that, on average, drilling noise is the loudest sound level to which a roof bolting machine operator would be exposed and contributes significantly to the operators' noise exposure. NIOSH has determined that the drill steel radiates a significant amount of noise during drilling and has conducted research to evaluate a damped drill steel to reduce noise radiation. The paper documents the research to date of this damped drill steel. Laboratory testing confirms that the concept of a damped drill steel would reduce sound levels generated during drilling, and by extension, operator noise dose exposure.

1 INTRODUCTION

Noise-induced hearing loss (NIHL) is the most common occupational disease in the United States today. Roughly 30 million workers are exposed to excessive noise levels or toxicants that are potentially hazardous to their hearing[1]. And every day, 80% of the Nation's miners work in an environment where the time-weighted average (TWA) sound level exceeds 85 dB(A). Moreover, 25% of the miners are exposed to a TWA sound level that exceeds 90 dB(A), the Permissible Exposure Limit (PEL) as specified by the Mine Safety and Health Administration (MSHA)[1]. Additional studies indicate that 70 to 90% of all miners have NIHL great enough to be classified as a hearing disability. Data collected by MSHA has shown that roof bolting machine (RBM) operators are the second most likely type of underground mining equipment operators to be over exposed to noise, per the MSHA PEL. In response to this, the National Institute for Occupational Safety and Health (NIOSH) initiated a project to develop noise controls for roof bolting machines.

[1)] **Disclaimer:** The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health

[a)] Email address: JPeterson@cdc.gov
[b)] Email address: HCarmargo@cdc.gov

2 DESCRIPTION OF RBM OPERATION

To ensure the safety of its workforce and prevent roof or rib falls, underground coal mines are required to develop and abide by a roof control plan. After the removal of coal or rock, the remaining strata could fall. The installation of roof bolts is one method to help prevent this. Shown in Fig. 1 is a roof bolting machine in a test facility at the Office of Mine Safety and Health research. Underground, the operator trams the RBM into position, installs a bit on a drill steel, places the drill steel in the RBM chuck and then drills the hole for the roof bolt. The operator removes the drill steel from the chuck, replaces it with a wrench for holding the roof bolt, inserts the resin into the hole, if used, drives the roof bolt into the hole with the RBM, then rotates the bolt for a predetermined length of time and thrust until the resin sets. The operator repeats this exercise as needed to meet the requirements of the roof control plan. Roof bolts of varying lengths, depending upon the roof control plan, are installed at roughly 1.2 m (four-ft) intervals. Commonly used roof bolts employ mechanical anchors, resin, rebar, or a combination of these to secure the bolt. There are also other types of roof bolts available. Examples of resin rebar roof bolts are shown in Fig. 2 and are available for holes drilled with a 2.5 cm (one-in) diameter bit or 3.5 cm (1.375-in) diameter bit. Drill steels are either round or hexagonal in shape (Fig. 3). Drill bits are available for vacuum drilling i.e., dry, and for mist or wet drilling (Fig. 4).

Drill steels are hollow. During vacuum, or dry drilling, vacuum air flowing from the drill bit to a dust box carries media particulates away from the operator, reducing dust hazards. During wet drilling, water is injected through the drill steel and exits through ports on the drill bit. Thus, treating the inside of the drill steel would present a myriad of problems. Most significantly, doing so would decrease the inside diameter of the drill steel, restricting air and particulate flow away from the drill bit (vacuum drilling), or mist or water flow to the drill bit where those drilling methods are employed. Either way, the smaller inside diameter would increase the chances of the drill steel clogging, and reduce productivity. Thus, to facilitate evaluating a damped drill steel prototype, treating the outside of the drill steel was deemed most appropriate.

3 UNDERGROUND FIELD EVALUATIONS

NIOSH conducted underground testing at cooperating coal mines to determine the noise levels and time spent performing the typical tasks required of a RBM operator[2]. A time motion study of an operator's shift comprised logging each activity for the time spent conducting a particular activity (e.g., tramming the machine, drilling holes, installing the roof bolt, etc.) and the noise levels associated with these tasks. Analysis of this data revealed the tasks an operator devoted the most time to, the noise dosage accumulated during each task, and the tasks which are the primary contributors to the operators' noise dose exposure. Results of these studies confirmed that the drilling task of the duty cycle exposed the operator to the highest noise levels. Figs. 5 through 7 show data collected at two mines of four RBM operators. In Fig. 5, it is shown that each operator is exposed to significantly higher noise levels when drilling than bolting. This is particularly the case for Operator A2. This operator was inexperienced, had difficulty aligning the drill steel, and on occasion the drill steel rubbed against a roof bolting strap. Figure 6 shows that each operator accumulates noise dose much more rapidly when drilling than bolting. Figure 7 shows the average time to drill and bolt a hole given instances where three of the four operators were observed drilling and bolting singly. It takes each operator much longer to drill a hole than to install a bolt. Given this, if RBM operator noise exposures are to be reduced, then drilling noise must be reduced.

4 METHOD OF TREATMENT TO BE EVALUATED

Past research has shown that drill steel/rod vibration is a common source of noise during drilling operations[3,4]. Further, NIOSH research has shown that accelerations in a roof bolting machine drill steel may exceed 500 g's, suggesting that this is the cause of significant noise radiation during roof drilling. This is the case for either round or hexagonal shaped drill steels. This vibration testing also included measuring vibration on the drill head, slinger plate, drill guide, and on the drill media. However, drill steel vibration proved to be the most severe. In this case, NIOSH investigated a constrained layer damping technique to modify a hexagonal drill steel. The drill steel vibration induced by drilling could be reduced by a vibration damping material used with a constraining layer to encapsulate a drill steel and reduce noise radiation.

NIOSH has investigated additional approaches to reduce drilling noise levels at the RBM operator's location. These include the use of a barrier, in the form of a Collapsible Drill Steel Enclosure (CDSE)[5]. Another approach involves vibration damping, in the forms of bit and chuck isolators[6]. Thus, a variety of techniques were investigated to provide mine operators options to address RBM operator noise over-exposures

Shown in Fig. 8 is a 4.1 cm (1.625-in) vacuum drill bit mounted on a standard hexagonal drill steel. To reduce noise emissions, a damped drill steel using a constraining layer was implemented. This modified drill steel comprises a standard hexagonal drill steel, and a steel casing, folded and seam welded to encase the drill steel and function as a constraining layer. Between the drill steel and casing was a vibration damping elastomer. Surfaces were bonded with epoxy. Applying the constraining layer damping elastomer increased the outside diameter of the damped drill steel, necessitating drilling with 4.1 cm (1.625-in) bits (Fig. 9). While increasing the outside diameter of the drill steel presents some problems, e.g., the requirement for larger diameter drill bits and roof bolts, for the sake of evaluating the concept via a prototype, this was acceptable.

5 DISCUSSION OF TEST RESULTS

Shown in Fig. 1 is a RBM, a granite block to serve as a drilling media, and a support structure for the granite. Located near the RBM operator was a B&K type 4188 microphone for operator ear sound level measurements (Fig. 10). Beamforming was the Noise Source Identification technique employed in prior stages of the RBM project to determine that the drill steel radiated a significant amount of noise. This analysis was again conducted to compare the noise radiated by a standard hexagonal drill steel with that of a damped drill steel. Shown in Fig. 11 are Beamforming data collected during drilling with the RBM configured to drill as shown in Table 1. Shown in Fig. 12 are similar data collected when drilling with the damped hexagonal drill steel. Both Figs. 11 and 12 were color scaled from 74 to 84 dB(A) and show noise level data in the one-third-octave band range of 100 Hz through 10 kHz.

At the operator's location, drilling with a standard hexagonal drill steel yielded sound levels on the order of 101 dB(A), an average for three, 30 second tests. Similar data collected during modified hexagonal drill steel drilling yielded an overall level of 97 dB(A) at the operator position, showing a reduction of 4 dB . Shown in Fig. 13 are one-third-octave band data of the operator location sound levels. Of particular importance are the one-third-octave bands 1,600 Hz through 6,300 Hz. In this range, each one-third-octave band sound level exceeds 85 dB(A). If a noise control is to provide sound level reduction, then it must be effective within this frequency range. Shown in Fig. 14 are the one-third-octave band frequency contributions to the overall A-weighted sound level. For the standard hexagonal steel, essentially all of the sound pressure is radiated within this frequency range, 100.7 dB(A) of an overall 101.2 dB(A). Using a damped drill steel reduced the sound levels in this frequency range by 5 dB. Because the RBM operator works in close proximity to the drill steel, and accumulates a significant portion of exposure during drilling, reductions in noise radiation using a damped drill steel are expected to reduce noise exposure.

6 SUMMARY / CONCLUSIONS

Past research has shown that drill steel/rod vibration is a common source of noise during drilling operations. Research by NIOSH has shown that accelerations in a roof bolting machine drill steel may exceed 500 g's, suggesting that this is a significant cause of noise during roof drilling. Thus, NIOSH developed a prototype damped drill steel to confirm the concept that a constrained layer drill steel would reduce noise levels at the operators' position. Laboratory testing confirmed that this is true, reducing the overall sound level at the operators' location by 4.3 dB in this case. Because the RBM operator works in close proximity to the drill steel, and drilling noise is a significant contributor to RBM operator noise exposure, using a damped drill steel is expected to reduce these exposures. This research supports a NIOSH research objective of reducing noise induced hearing loss.

7 ACKNOWLEDGEMENTS

The authors wish to thank David Yantek, Research Engineer, as well as Lynn Alcorn and Pat McElhinney, Physical Sciences Technicians, for their respective contributions in designing and fabricating a damped hexagonal drill steel. All are NIOSH OMSHR employees in Pittsburgh, PA.

8 REFERENCES

1. National Institute for Occupational Safety and Health (NIOSH), National Occupational Research Agenda, Cincinnati, OH: U.S. Department of Health and Human Services, DHHS (NIOSH) Publication No. 96-115, (1996).

2. J.S. Peterson and L. Alcorn, "Results of noise measurements from underground testing of a roof bolting machine duty cycle", *NoiseCon07*, (2007).

3. I. Hawkes and J.A. Burks JA, "Investigation of Noise and Vibration in Percussive Drill Rods", *Int. J. Rock, Mech, Min. Sci. & Geomech,* Abstr, (1979).

4. I. Carlvik I, "The Generation of Bending Vibrations in Drill Rods", *Int. J. Rock, Mech, Min. Sci. & Geomech*, Abstr, (1981).

5. J.S. Peterson, "Collapsible Drill Steel Enclosure for Reducing Roof Bolting Machine Drilling Noise", *NIOSH Technology News No. 532*, (2008).

6. J.S. Peterson, P. Kovalchik and D. Yantek, "Development of Roof Bolting Machine Bit and Chuck Isolators for Drilling Noise Reductions", *ASME 2009 International Mechanical Engineering Congress & Exposition*, (2009).

Table 1 – Drilling test setup.

Drill bit dia., standard hex drill steel (cm / in)	4.1 / 1.625
Drill bit dia., damped hex drill steel (cm / in	4.1 / 1.625
Drill steel length (cm / in)	122 / 48
Rotation speed (rpm)	230
Thrust (kN / lbs)	9.4 / 2,121
Drill media	granite

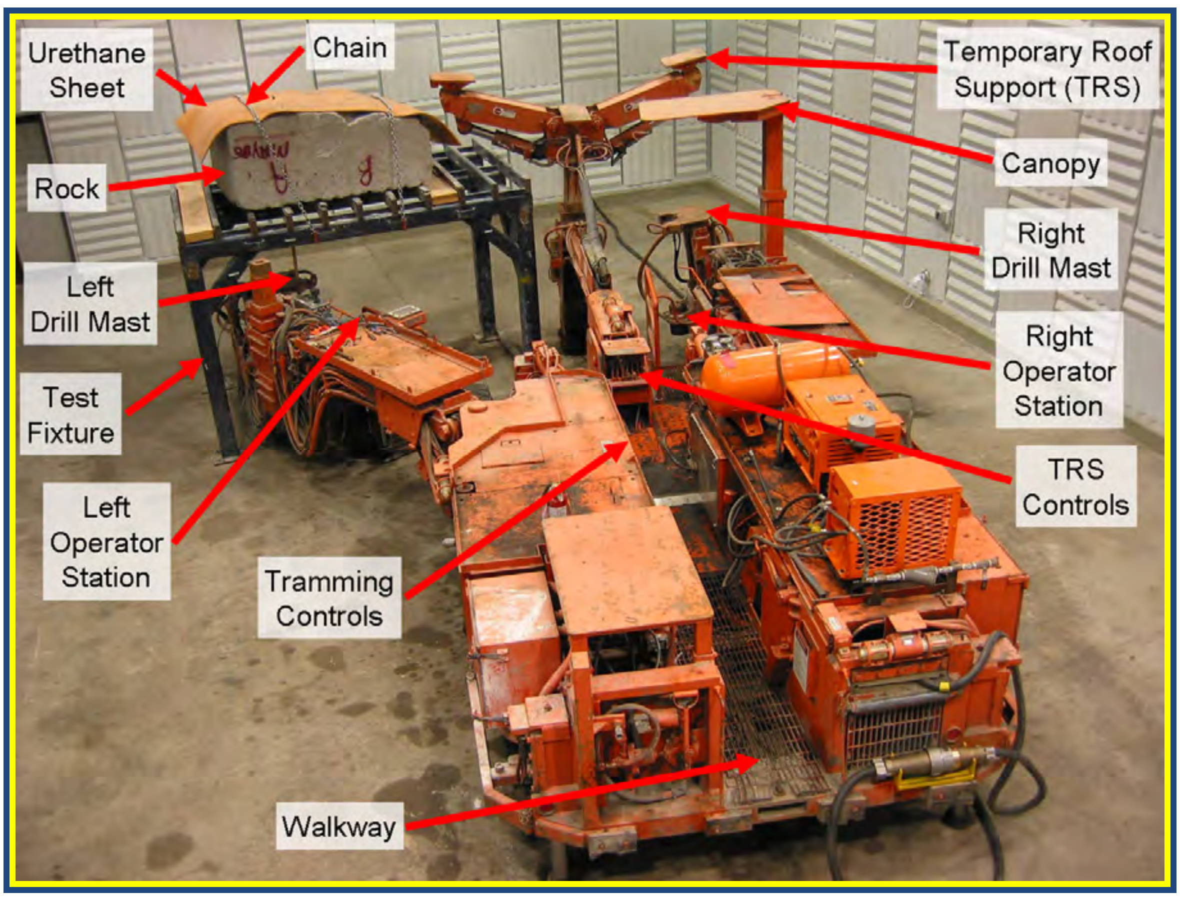

Fig. 1 - Roof bolting machine and drill media located in the hemi-anechoic chamber.

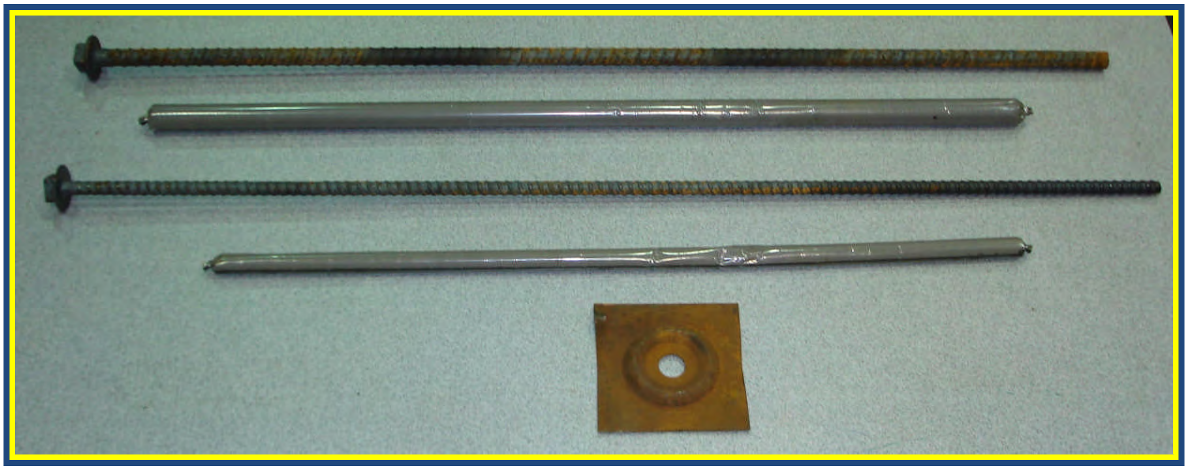

Fig. 2 - Resin and roof bolts, 3.5 cm (1.375-in) [top], 2.5 cm (1-in) [middle] and plate [bottom].

Fig. 3 - Drill steels, hexagonal [top], and round [bottom].

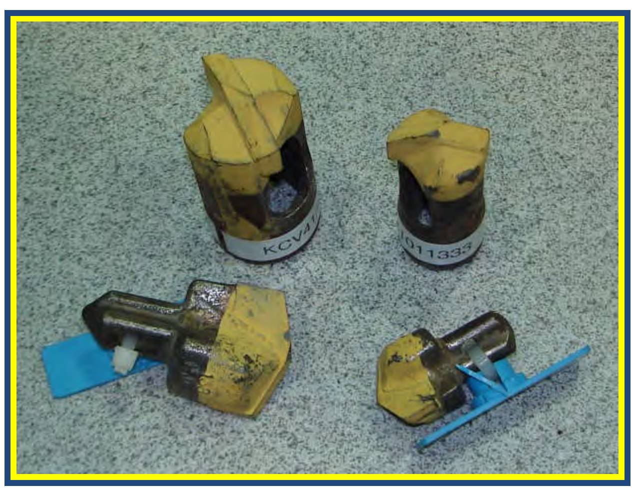

Fig. 4 - Drill bits, vacuum [top] and wet or mist [bottom].

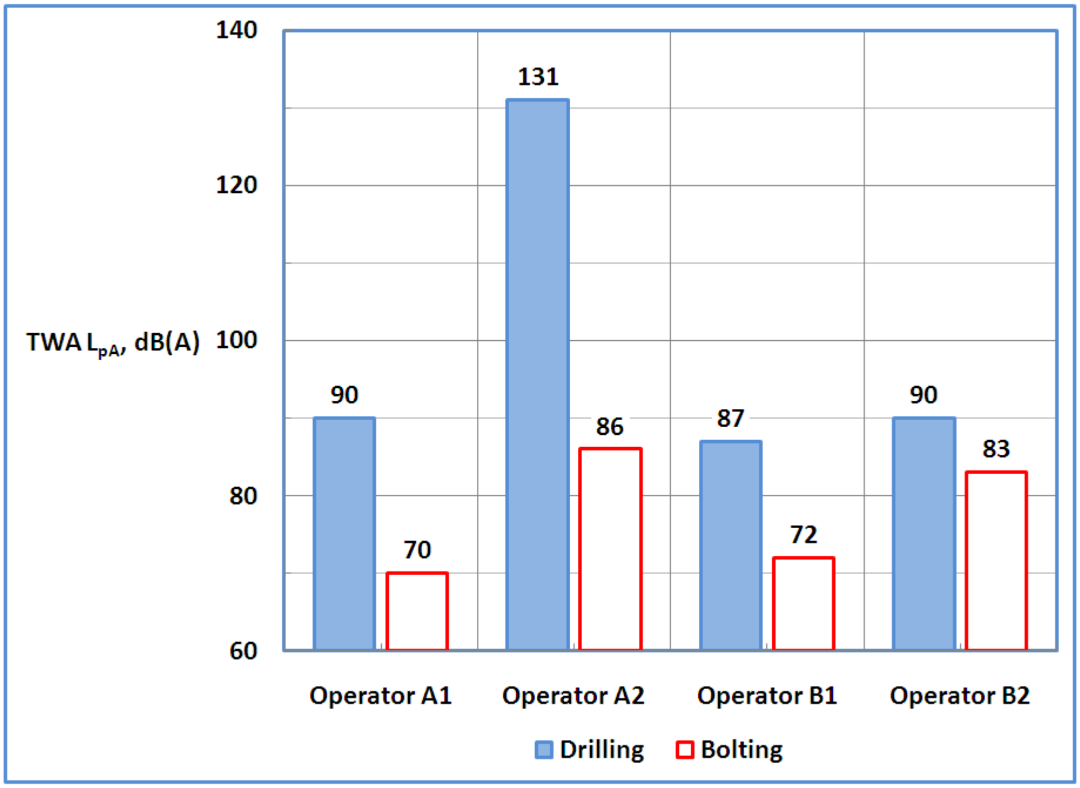

Fig. 5 - RBM operators noise levels during drilling and bolting.

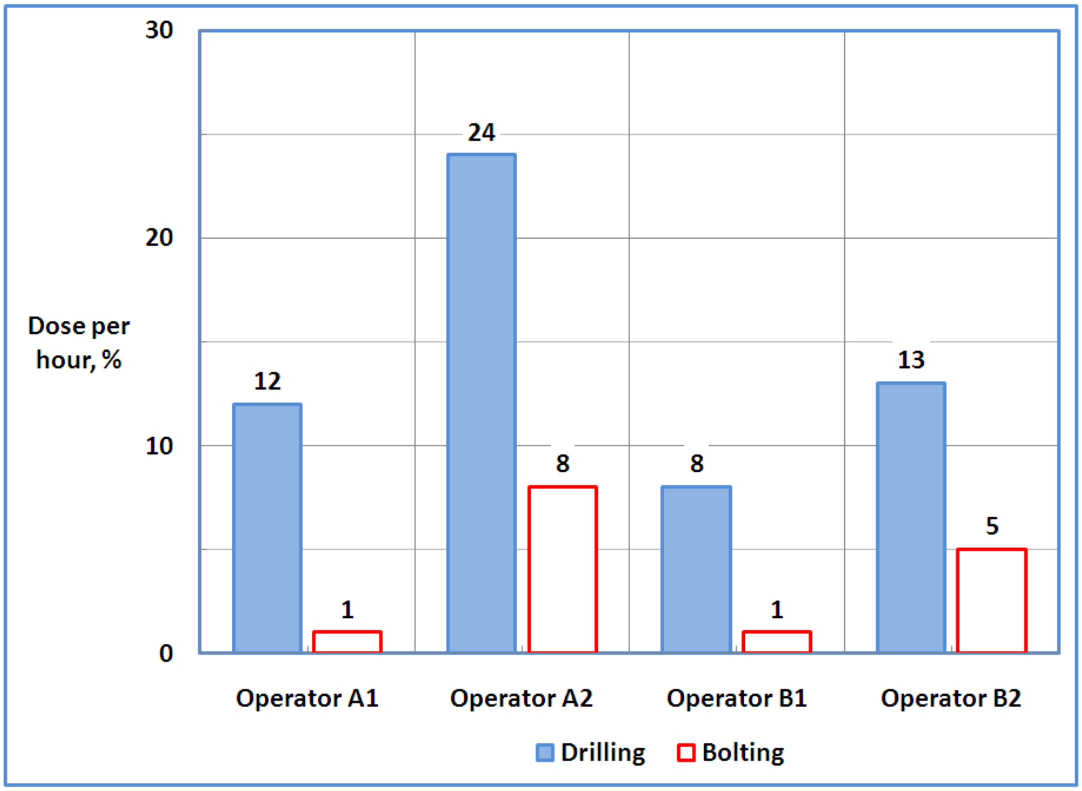

Fig. 6 - RBM operators dose accumulation rate when drilling and bolting.

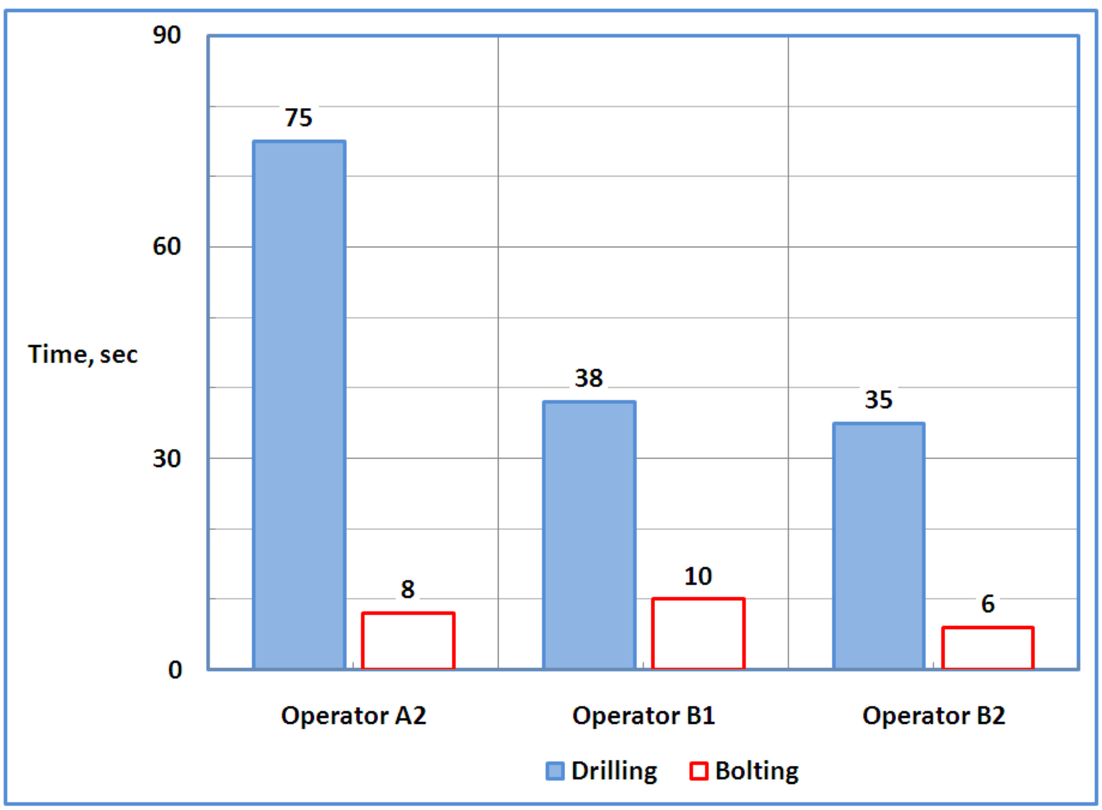

Fig. 7 - RBM operators average time to drill and bolt a hole.

Fig. 8 - Standard hexagonal drill steel and 4.1 cm [1.625-in] bit

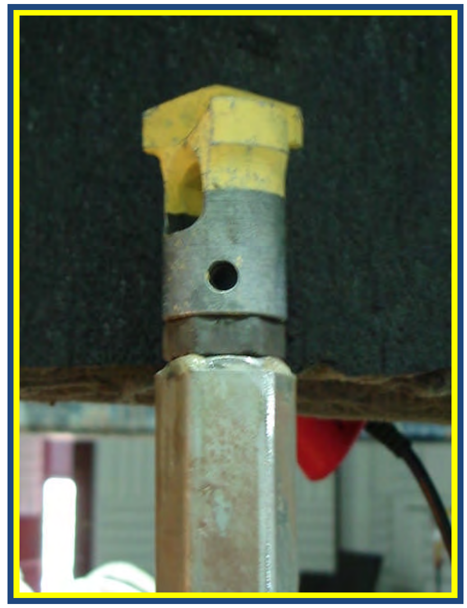

Fig. 9 - Damped hexagonal drill steel and 4.1 cm [1.625-in] bit

Fig. 10 - Operator ear microphone location.

Fig. 11 - Beamforming data collected during standard hexagonal drill steel testing.

Fig. 12 - Beamforming data collected during damped hexagonal drill steel testing.

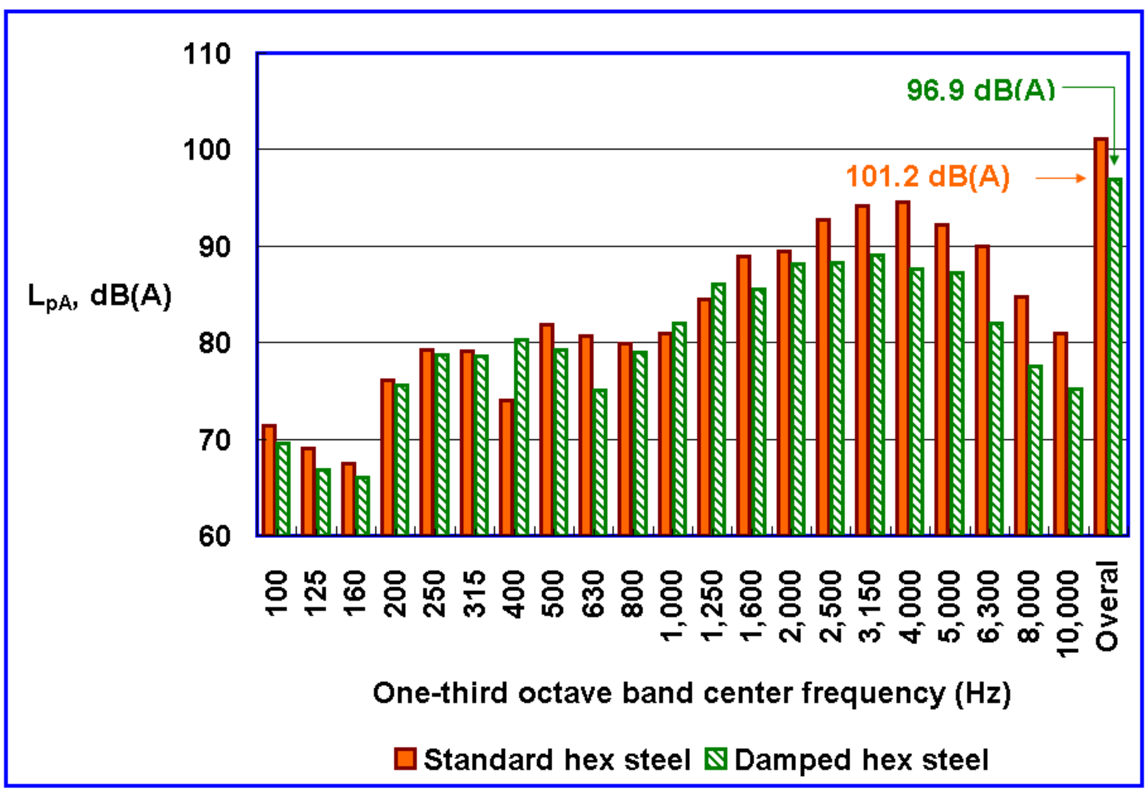

Fig. 13 – A-weighted sound power level when drilling with a standard hex drill steel and a damped hex drill steel.

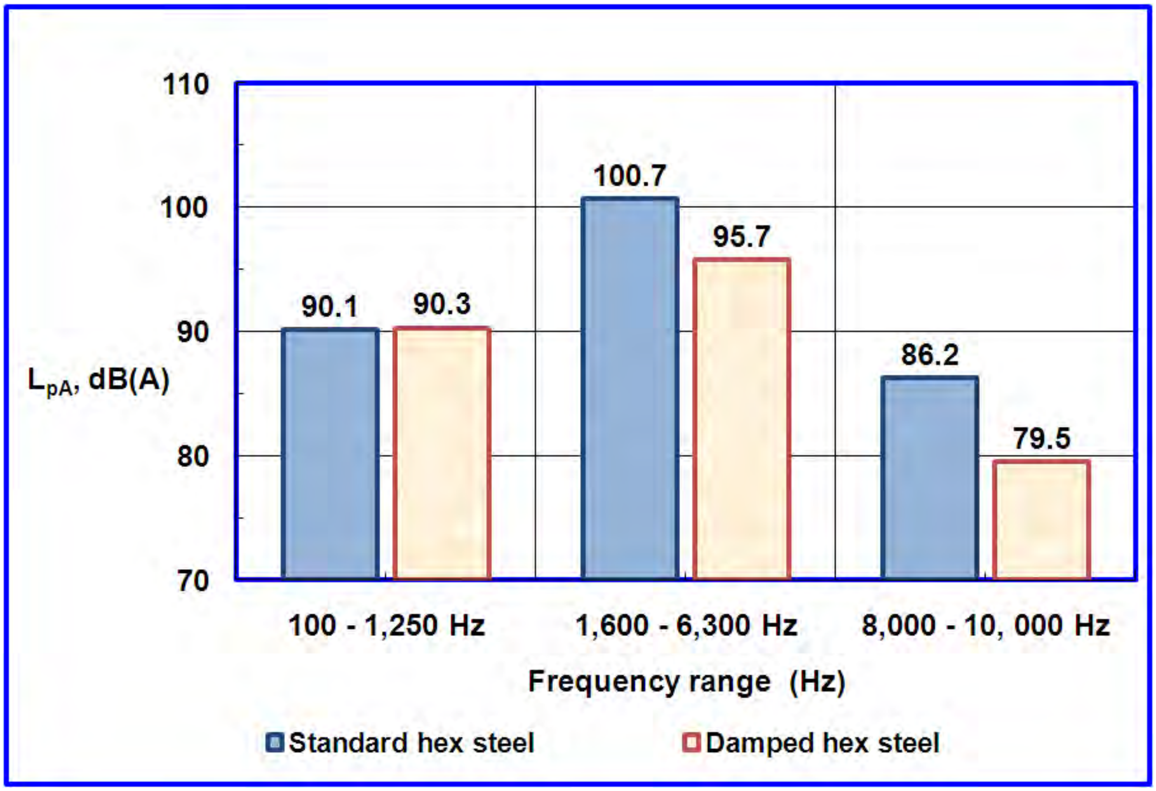

Fig. 14 – A-weighted sound power level contributions of selected frequency ranges.