DEVELOPMENT OF ROOF-BOLTING MACHINE BIT AND CHUCK ISOLATORS FOR DRILLING NOISE REDUCTIONS

Jeffrey Shawn Peterson
NIOSH
Pittsburgh Research Laboratory
Pittsburgh, Pennsylvania, USA

Peter G. Kovalchik
NIOSH
Pittsburgh Research Laboratory
Pittsburgh, Pennsylvania, USA

David Yantek
NIOSH
Pittsburgh Research Laboratory
Pittsburgh, Pennsylvania, USA

ABSTRACT

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 various underground coal mining equipment, an example of which is a roof bolting machine (RBM). After the removal of coal or rock, the remaining strata may be subject to fall, either from overhead (the roof) or from the side (the rib). One method used in underground coal-mines to prevent failures requires the installation of roof bolts. The roof bolting machine operator trams the machine to the required location, drills a hole into the strata, and then installs a roof bolt, supporting the roof or the rib, as the case may be. Field studies support the premise that, on average, drilling noise is the loudest noise that a roof bolting machine operator would be exposed to and contributes significantly to the operators' noise exposure. NIOSH has determined that the drill steel radiates a significant amount of noise during drilling. NIOSH is developing bit and chuck isolators to reduce vibration, and thus noise radiation of the drill steel, with the longer-term goal of reducing roof bolting machine operator noise exposure. Laboratory testing has shown that operator ear sound pressure levels may be reduced by 3 to 7 dB(A), depending upon the test configuration and drilling media.

INTRODUCTION

Hearing loss prevention is one of 21 Priority Research Areas listed in the NIOSH National Occupational Research Agenda [1]. Further, the Department of Labor Mine Safety and Health administration (MSHA) collects noise sample data that assists NIOSH in selecting equipment whose operators are most likely to be over exposed to noise [2]. Such data collected from 2000 to 2005 show that only seven types of machines compose the bulk of the equipment whose operators exceed 100% noise dosage, per the MSHA Permissible Exposure Level (PEL) (Table 1). Of these machines, the roof bolting machine operator was the second most likely to be over exposed among operators of all equipment used in underground coal.

Table 1 - Percentage of noise over-exposures by machine

Machine	%
Continuous mining machine	35
Bull dozer	24
Roof bolting machine	17
Front end loader	8
Shuttle car	6
Auger miner	5
Truck	5

Commonly used roof bolts employ either mechanical anchors to secure the bolt, resin and rebar to serve the same purpose, or both. There are other types of roof bolts available as well. Examples of resin rebar roof bolts are shown in Figure 1. Drill steels are either round or hexagonal in shape and are available to mate with either 2.54 cm (one inch) or 3.49 cm (1 3/8 inch) drill bits (Figure 2). Drill bits are available for vacuum drilling i.e., dry, and for mist or wet drilling (Figure 2). Underground, the operator trams the roof-bolting machine to the required location, 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 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 torque until the resin sets. The operator repeats this exercise, installing rows of bolts across the roof as specified in the mines roof control plan, typically every 1.2 m (four-ft).

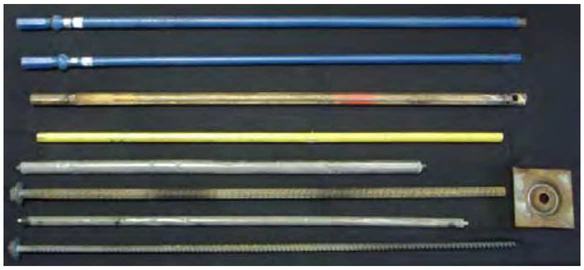

Figure 1 - Drill steels (round & hex), bolt plate, resin and resin type roof bolts, shown for 2.54 and 3.49 cm bit drilling and bolting

Figure 2 - Drills bits; vacuum (top), wet (bottom), 2.54 and 3.49 cm

Prior underground time-motion studies confirmed that RBM operators are exposed to the highest noise levels when drilling as opposed to bolting, tramming, and other tasks associated with their typical work day [3]. Essential to developing engineering noise controls to reduce the occurrences of Noise Induced Hearing Loss (NIHL) for roof bolting machine operators is to develop engineering noise controls to reduce drilling noise. The objective is to reduce an operators' noise exposure to a time-weighted average (TWA) of 90 dBA or less for an eight hour shift. This would correspond to a noise dose of 100%, the maximum allowed per the MSHA PEL. A suite, or combination, of controls, is the most promising path of success to meet the objective. To this end, NIOSH is pursuing several engineering controls to reduce drilling noise. This paper discusses research results for bit and chuck isolators.

DRILLING ACCELERATION TESTING

In percussive rock drilling, one notable source of noise generation is drill rod vibration [4,5]. There are three fundamental ways to reduce these vibrations, and thus noise: reduce the cause of the vibration, attenuate the vibration, or attenuate the noise. Early laboratory testing included measuring vibration on the drill head, slinger plate, drill guide, and on the drill media. NIOSH also measured acceleration on the drill steel and employed a slip ring assembly to dress acceleration signals to data acquisition equipment (Figure 3). Figure 4 shows acceleration levels measured on a hexagonal drill steel and a 3.49 cm (1 3/8") bit during a 5-second sample (rotation speed of 200 rpm and thrust of 9.4 kN). NIOSH used granite as the drill media to represent high compressive strength roof and for the fact that this compressive strength should remain consistent throughout the drilling, helping to ensure test repeatability. Levels peaked at more than 500 g's, confirming that during drilling, there is significant vibration in the drill steel.

Figure 3 - Drill steel accelerometers and slip-ring assembly

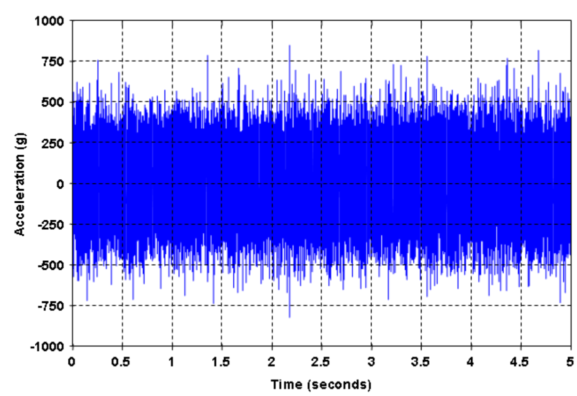

Figure 4 - Typical drill steel acceleration, hexagonal drill steel, 3.49 cm bit, granite drill media

HEMI-ANECHOIC CHAMBER BEAMFORMING AND SOUND LEVEL TESTING

NIOSH maintains a hemi-anechoic chamber at PRL for noise source identification purposes. Key to this testing is a 42-

microphone Bruel and Kjaer beamforming array and associated data acquisition system and analysis software. Early chuck isolator laboratory testing comprised beamforming analysis to locate noise sources and a supplemental microphone placed near the RBM operators head to collect operator ear sound level measurements. Table 2 lists the drilling configuration for this testing.

Table 2 - Drilling configurations

Drill media	granite
Rotation speed (rpm)	230
Thrust (kN)	9.4 or 22
Drill bit (cm)	3.49
Drill steel type	hexagonal
Drilling type	vacuum

A jaw-type shaft coupling used as a chuck isolator served as a simple device to test the premise that breaking the mechanical link between the drill steel and the drill chuck would reduce noise levels at the operator's ear position (Figure 5). Shown in Figures 6 and 7 are operator ear sound level data collected using a typical hexagonal drill steel (baseline) and when using the jaw-type coupling. Sound levels are reduced in the most relevant one-third octave band frequencies of 1,600 Hz through 6,300 Hz (shaded area of Figures 6 and 7). Relevant one-third octave frequencies are defined as those in which greater than 90% of the noise energy are contained. Overall, using the jaw-type coupling reduced the operators sound level to 96 dBA from a baseline measurement of 100 dBA for the 9.4 kN thrust pressure testing and from 104 dBA to 100 for the 22 kN thrust tests (Table 3).

Figure 5 - Jaw-type coupling with 58 Shore D urethane spider

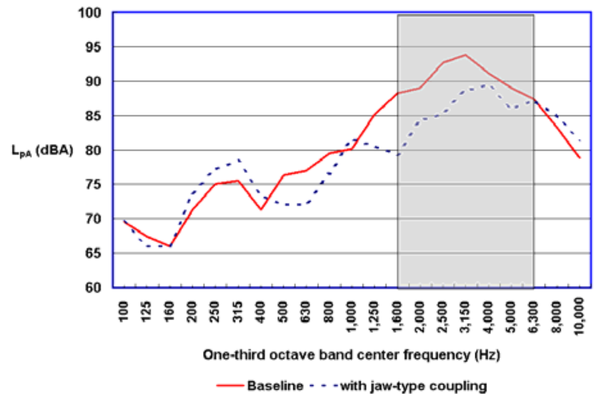

Figure 6 - Operator ear sound pressure level, 9.4 kN thrust, four dBA reduction using a jaw-type coupling

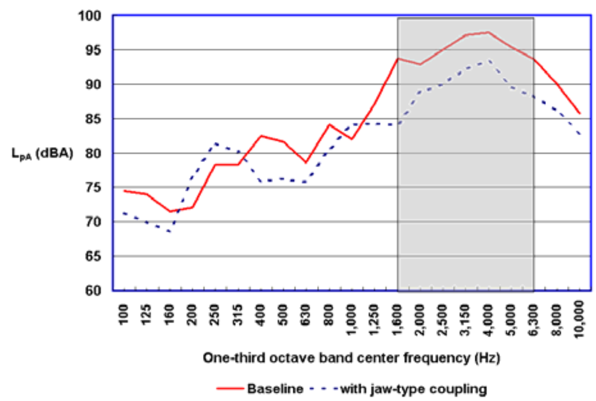

Figure 7 - Operator ear sound pressure level, 22 kN thrust, four dBA reduction using a jaw-type coupling

Table 3 – Sound pressure level, A –weighted decibels Average of three tests

	9.4 kN thrust		**22 kN thrust**	
	Overall	**1.6 kHz – 6.3 kHz**	**Overall**	**1.6 kHz – 6.3 kHz**
Baseline	100 [A]	99	104 [B]	104
Jaw-type coupling	96 [B]	95	100 [A]	99
Reduction	4	4	4	5
Bit isolator	97 [C]	97	----	----
Reduction	3	2	----	----
Combination	92 [B]	90	----	----
Reduction	7	9	----	----

[A] – standard deviation of 0.4 dBA
[B] – standard deviation of 0.6 dBA
[C] – standard deviation of 1.6 dBA

Additional testing using the beamforming array showed that the steel radiates a significant amount of noise during drilling [6]. Figure 8 shows baseline data collected during testing using a thrust of 9.4 kN. The noise sources are centered roughly 10 to 20 cm (4 to 8 inches) below the drill bit/media interface and above the drill chuck. As the drill steel advances during cutting, the lower drill steel noise source advances with it, while the upper source essentially remains the same. Figure 9 shows similar drilling but with the inclusion of the jaw-type coupling. Both Figures 8 and 9 show spectral data in the 1.6 kHz through 6.3 kHz one-third octave band frequency range and are scaled from 75 to 85 dB. The differences between the baseline data and that collected using the coupling are significant. The operator ear sound level is reduced from 100 to 96 dBA and the beamforming results change dramatically. For the given frequency range, the chuck area drill steel noise source is reduced below 75 dB and the upper source is reduced to roughly 80 dB. Given these results, NIOSH deemed chuck isolation as a viable option to reduce noise generation during roof bolting drilling.

Figure 8 - Beamforming of baseline drilling, 100 dBA @ the operators' position

Figure 9 - Beamforming of drilling with the jaw-type coupling, 96 dBA @ the operators' position

NIOSH also considered a bit isolation approach to reducing the vibration, and thus noise generation, of the drill steel at the steel-bit interface. The initial prototype was a modified vacuum chuck coated with 60 Shore D urethane, hereafter referred to as a bit isolator (Figure 10). Shown in Figure 11 are operator ear sound level data collected using a typical hexagonal drill steel (baseline) and when using the bit isolator. As with the chuck isolator, sound levels are reduced in the most relevant one-third octave band frequencies of 1,600 Hz through 6,300 Hz (shaded area of Figure 11). Overall, using the bit isolator reduced the operators sound level to 97 dBA from a baseline measurement of 100 dBA for the 9.4 kN thrust pressure testing (Table 3).

Figure 10 – Bit isolator with 60 Shore D urethane coating

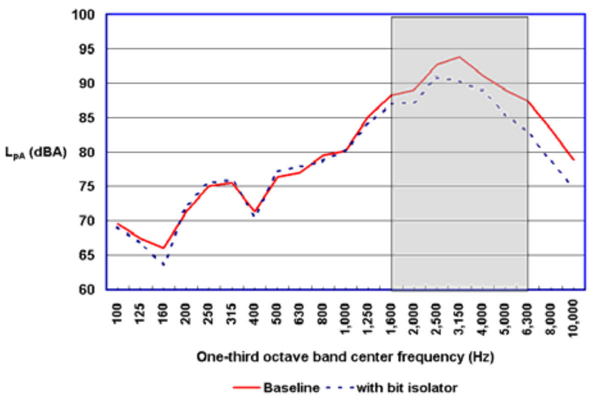

Figure 11 - Operator ear sound pressure level, 9.4 kN thrust, three dBA reduction using a bit isolator

In combination, the bit and chuck isolators reduced the RBM operators sound level by 7 dBA (Table 3). Shown in Figure 12 is the one-third octave band plot of the operators sound level. Here, the significant reduction in the operators sound level is prominently shown in the frequency range of importance, 1.6 kHz through 6.3 kHz.

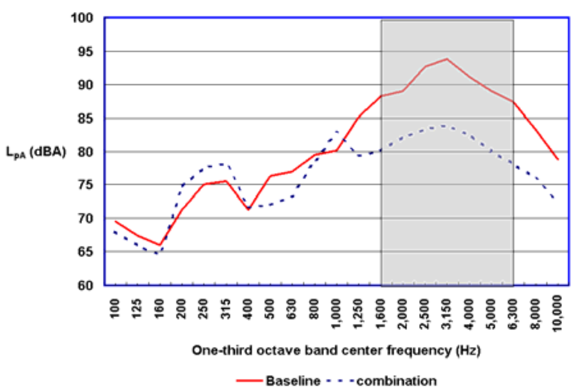

Figure 12 - Operator ear sound pressure level, 9.4 kN thrust, seven dBA reduction when using a chuck and bit isolators in combination

REVERBERATION CHAMBER SOUND POWER LEVEL TESTING

NIOSH also maintains a reverberation chamber used to measure the overall noise emission of mining and construction equipment via sound power level testing. This testing is conducted per ISO 3743-2 (engineering grade and used for this analysis) as well as precision grade testing per ISO 3741/ANSI S12.51. The testing configurations were the same as listed in Table 2. Shown in Figure 13 is the sound power level data for baseline and coupling testing conducted at a thrust of 9.4 kN. Here, the sound power level for the baseline condition was 110 dBA; with the inclusion of the coupling, the sound power drops to 107 dBA, a three-decibel reduction (Table 4). As for the sound pressure level testing discussed earlier, noise levels are reduced in the most relevant one-third octave band frequencies of 1.6 kHz through 6.3 kHz (shaded area of Figure 13).

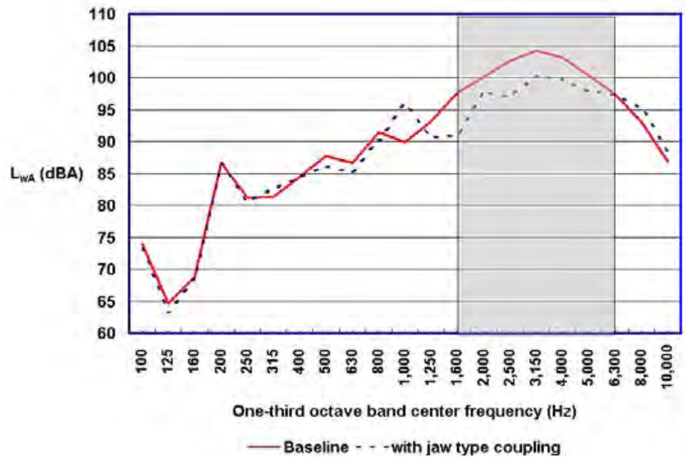

Figure 13 – Sound power level per ISO 3743-2, 9.4 kN thrust

Figure 14 shows similar results for testing conducted at 22 kN thrust. Here, the inclusion of the jaw type coupling reduced the sound power level from 114 dBA to 110 dBA. Table 4 summarizes sound power levels, broken down as overall values and a summation of the levels in the 1.6 kHz through 6.3 kHz one-third octave frequency bands. This data confirms that the significant portion of the sound power levels is contained within 1.6 kHz and 6.3 kHz one-third octave band frequency ranges, and the reductions gained by using the coupling reduce the sound levels in these important frequency bands.

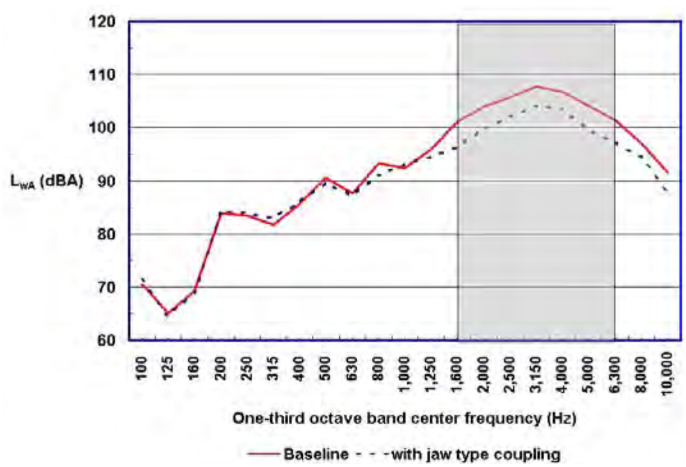

Figure 14 - Sound power level per ISO 3743-2, 22 kN thrust

Table 4 – Sound power level, A –weighted decibels Average of three tests

	9.4 kN thrust		22 kN thrust	
	Overall	**1.6 kHz – 6.3 kHz**	**Overall**	**1.6 kHz – 6.3 kHz**
Baseline	110 [C]	110	114 [A]	113
Jaw-type coupling	107 [D]	106	110 [B]	110
Reduction	3	4	4	3
Chuck isolator 1	108 [B]	107	----	----
Reduction	2	3	----	----
Chuck isolator 2	109 [B]	108	----	----
Reduction	1	2	----	----

[A] – standard deviation of 0.2 dBA
[B] – standard deviation of 0.3 dBA
[C] – standard deviation of 0.4 dBA
[D] – standard deviation of 0.6 dBA

As an extension of this work, NIOSH developed and tested a chuck isolator (Figure 15) in the reverberation chamber. This chuck isolator consists of two steel parts, a cylindrical outer sleeve with three drivers, located 120 degrees apart; and a center chuck section, also with three drivers located at 120 degrees apart. Between these is 58 Shore D polyurethane, bonded to all surfaces and served to break metal-to-metal contact between the drill chuck and the drill steel. Testing at a thrust of 9.4 kN, using the chuck isolator reduced the sound power emission from 110 to 108 dBA (Figure 16). Moreover, as was the case with the jaw-type coupling, this reduction is attributable to reductions in the relevant frequency range of 1.6 kHz through 6.3 kHz (Table 4).

NIOSH also tested a second chuck isolator, this time with the outer sleeve and the center chuck section using four drivers located 90 degrees apart (Figure 17). The chuck section is "floating" in 45 Shore A polyurethane. Figure 16 also shows sound power levels for this chuck isolator 2 and the results illustrate a reduction of 1 dBA compared to the baseline data. Here, reductions in the sound power are in the 800 Hz through 1.6 kHz one-third octave bands and do not adequately reduce levels in the preferred frequency bands.

Figure 15 - Chuck isolator 1, 58 Shore D polyurethane filled

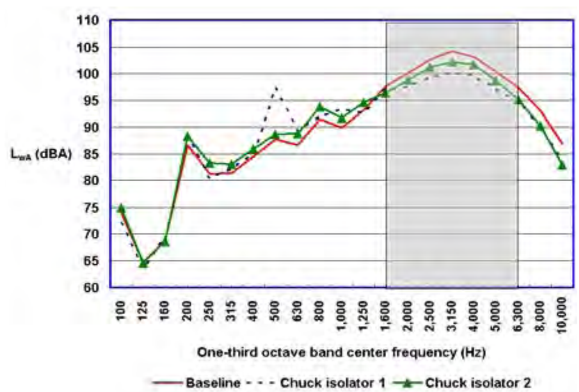

Figure 16 - Sound power level per ISO 3743-2, chuck isolators

Figure 17 - Chuck isolator 2, 45 Shore A polyurethane filled

FIELD TESTING OF A CHUCK ISOLATOR

NIOSH continued testing of a chuck isolator (Figure 18), similar to chuck isolator 2, the same general driver design and 45 Shore A polyurethane damping material. However, this chuck isolator contained an internal dust collector funnel/sleeve to ensure that the vacuum system maintained suction under heavy loading.

Figure 18 – Chuck isolator 3, 45 Shore A polyurethane filled, used for field testing and dose accumulation model

NIOSH was granted the opportunity to field test this chuck isolator at a co-operating coal mine. There, NIOSH conducted time-motion studies and dosimetry on the operators of a dual-boom J.H. Fletcher roof bolting machine. The operators were observed drilling normally, without using a chuck isolator, for an entire shift. Of the two operators, one was an experienced operator while the other was new to operating a RBM. The more experienced operator drilled more smoothly and consistently and was the primary focus of the time motion study for this evaluation. During the shift, this operator drilled and bolted 106 holes and accumulated 67.2% noise dose exposure (Table 5). Based on this, the operator accumulated 12.7% dose per 20 bolts.

NIOSH did not collect a full shift of data using chuck isolator 3 due to maintenance considerations at the mine. But, NIOSH also was able to test the chuck isolator during a simulated drilling and bolting exercise where the operator installed 20 bolts using chuck isolator 3. All other test conditions were as close as possible to the data collected drilling normally, same mine section, same RBM and set-up, and the same RBM operator. Using chuck isolator 3, the operator accumulated 7.7 % dose when installing the 20 roof bolts (Table 5).

Table 5 – RBM operator noise dose accumulation data

	Drilling normally	Drilling with a chuck isolator
Number of holes	106	20
Accumulated dose (%)	67.2	7.7
Dose per 20 holes (%)	12.7	7.7

For simplicities sake and for comparative purposes, a modeled shift was developed. In the model, a pair of operators completes ten rows of four bolts across, (20 bolts per operator) comprising a “cut” in this example. It is also assumed that the pair of operators completes ten “cuts” per ten-hour shift. This would entail installing 200 bolts per day each. Shown in Table 6 is how the ten-hour shift is broken up, with 30 minutes travel time at the beginning and end of the shift, a 30 minute lunch, and 4:15 minutes of roof bolting both before and after lunch. To illustrate, given five cuts before lunch, an operator accumulating 12.7% dose per cut would accumulate 63.5% dose, or 14.9% dose per hour for 4:15 (Table 6). Shown in Figure 19 is the modeled shift noise dose accumulation for a RBM operator. In this model, using a chuck isolator reduces the RBM operator’s 8-hour shift exposure 106% to 67% and the time weighted average from 92 dBA to 89 dBA. This is important, as MSHA considers a 3 dBA reduction in exposure to be significant.

Table 6 – Dose accumulation model

Task	Time (hrs)	Dose accumulation rate (% / hour): Normally	Dose accumulation rate (% / hour): With Chuck isolator
Elevator and mantrip in	0.5	2.6	2.6
Installing bolts	4.25	14.9	9.1
Lunch	0.5	0.0	0.0
Installing bolts	4.25	14.9	9.1
Elevator and mantrip out	0.5	2.6	2.6

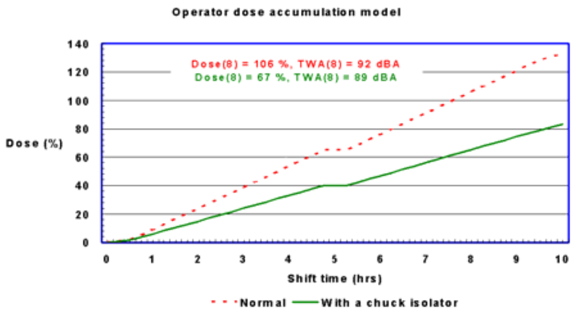

Figure 19 – RBM dose accumulation model, drilling normally and with a chuck isolator

NIOSH is continuing to pursue a suite of engineering noise controls to reduce RBM operator noise dose exposures. Chuck and bit isolators are key components of this suite. The suite approach allows for mining companies to select the engineering noise control that best suits their needs. In cases where the RBM operator is nominally over-exposed to noise, either a chuck or a bit isolator may be used to bring the operators noise dose into compliance. Operators exposed to greater noise levels may require both, or additional noise controls as developed by NIOSH. This includes a Collapsible Drill Steel Enclosure (CDSE), which NIOSH has developed and field tested at cooperating mines [7]. THE CDSE creates an acoustic barrier between the noise source (drill steel) and the receiver (operator) to reduce noise levels at the operators position and can be used singly or in combination with bit and chuck isolators.

SUMMARY

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 the cause of significant noise during roof bolting drilling as well. Thus, chuck and drill bit isolation as a means to reduce drill steel vibration has been investigated. Early testing using a simple jaw-type coupling has shown reductions in operator ear sound levels as well as sound power. Early prototype chuck isolators have proven to also reduce noise emissions (sound power level) but to a lesser degree that the jaw-type coupling. A field study and dose accumulation model using a chuck isolator showed a three decibel reduction in operator noise exposure, a significant finding. Early prototype bit isolators also showed promise in reducing noise emissions. Research continues in this area for possible inclusion in a suite of engineering noise controls that should reduce drilling noise during roof bolting and thus, reduce noise exposures to the operator. This, in turn, supports a NIOSH research objective of reducing noise induced hearing loss.

ACKNOWLEDGMENTS

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