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ASSESSMENT OF NOISE CONTROLS COMMONLY USED ON JUMBO DRILLS AND BOLTERS IN WESTERN UNDERGROUND METAL MINES

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ABSTRACT

The mining industry has recognized the importance of engineering controls as a primary means of preventing hearing loss. The noise control treatments most commonly observed on drills and bolters during this study were windshields, sound absorbing material, and hydraulic motor covers. These controls were evaluated on machines at underground metal mines to determine the amount of noise reduction achieved by each control. The results indicate that absorbing material has very little effect on the noise level. The noise reduction attributable to the motor covers was dependent on the material used to create the cover. Properly installed windshields were the most consistent control.

INTRODUCTION/BACKGROUND

Noise induced hearing loss is the most common occupational illness in the United States today, with 30 million workers exposed to excessive noise levels (NIOSH, 1996). Of particular concern is the mining industry where many workers are exposed to damaging noise levels. As a result, approximately 90% of coal miners and nearly 70% of metal/nonmetal miners exhibit a hearing disability by age 50. (Franks 1996, 1997)

One of many reasons for the prevalence of hearing loss is the lack of successful engineering noise controls for the equipment used in the underground mining industry. The relatively small market for mining equipment combined with the unique requirements imposed by the sometimes hostile mining environment has limited both manufacturer innovation and the transfer of technology from other industries.

Fortunately, the mining industry has recognized the importance of engineering noise controls as a primary means of reducing noise exposure and preventing noise induced hearing loss among mine workers. And even though a lack of readily available proven control technology has hindered the implementation of controls, potential noise control solutions are being crafted and tried at the mine level by mine workers, operators, manufacturers, consultants, and government personnel.

A downside to this initiative is that in an attempt to reduce worker noise exposure, many operators install noise treatments without knowing how much noise reduction to expect from the treatment before installation, or how much noise reduction is actually achieved after installation. In some cases, due to improper material selection, placement, or installation, little to no sound reduction occurs after the application of noise treatments. In other cases, noise treatments are applied when the source sound level does not warrant treatment, thus wasting valuable resources. Not only do unsuccessful noise controls cost the industry time and money, they also do nothing to decrease the equipment operator's risk of noise induced hearing loss.

APPROACH

A short-term goal of the National Institute for Occupational Safety and Health (NIOSH) is to identify possible noise control solutions that are being applied to pieces of machinery and characterize the noise reduction attributed to those controls. In addition to locating and assessing existing controls, NIOSH is also identifying processes or machines in need of noise controls, identifying gaps in technology which impede the use of noise controls, and identifying barriers to the use of noise controls including collateral hazards. To commence this task, NIOSH surveyed seven underground metal mines located in the western United States that had installed noise controls on pieces of mining equipment.

During the course of the study noise controls installed on locomotives, haul trucks, face drills, roof bolters, and load-haul-dumps (LHDs) were evaluated using several acoustical measurement techniques. The results can be used by the industry as a guide to focus noise reduction and hearing conservation efforts on controls that show the most promise. Space does not permit the findings from all of the equipment tested or the results from each measurement technique to be presented here, so only the sound level results of the machines with the most installed engineering controls, specifically the jumbo face drills and roof bolters, will be discussed. The remainder of the findings will be published elsewhere, but a summary of all of the acoustical techniques used will be presented in the Methods Section.

METHODS

To determine the actual amount of noise attenuation achieved by each applied noise control at the machine operator position, measurements were made with and without the noise control treatments in place using several acoustic measurement techniques. Sound level and sound intensity measurements were performed using Bruel & Kjaer (B&K) 2260 Investigators running Enhanced Sound Analysis and Sound Intensity software respectively. The B&K Investigator is a precision Type I instrument (ANSI S1.4) that has a tolerance of 1 dB between 500 Hz and 4000 Hz. Noise exposure was measured using a Quest Q-400 Noise Dosimeter. The Quest Q-400 is a single microphone, dual channel device that allows for the simultaneous measurement of noise using two different evaluation criteria.

Sound Level Measurements

Sound level measurements were conducted on each piece of equipment underground, and, when possible, on the surface. On machines with more than one applied noise treatment, the testing was done in a manner which allowed for the determination of the reduction due to each treatment, as well as the overall reduction due to combinations of treatments.

For every machine tested, a one-third-octave Linear Equivalent Sound Pressure Level (Leq) spectrum was measured. The Leq is the average sound level over a measurement period. For these experiments the sound was averaged for at least 15 seconds. Before actual readings were recorded, background noise measurements were taken to insure that no extraneous noise was present that could corrupt the data.

Since the noise produced by the drilling and bolting processes can be highly variable, care had to be taken to insure a fair comparison was being made across conditions. To do this, a two-channel measurement system was used. One channel, used as a reference, measured the sound level outside of the operator area toward the drill steel; the other channel simultaneously measured the sound level at the operator's ear. This can be seen in Figure 1. Performing the measurements in this manner allowed changes in sound level at the operator to be attributable to the application or absence of the noise control and not a variation in source level caused by a change in geological conditions while drilling.

Figure 1. Two channel sound level measurement.

Sound Intensity Measurements

To quantify the reduction achieved by some of the noise control devices, sound intensity measurements were made on the machine surface. Sound intensity is a vector quantity that describes the rate of energy flow through a unit area (ANSI S12.12). From the intensity data, the localized sound power can be calculated. Comparing the sound power calculations with and without the noise control in place can be used to directly measure the performance of the control.

To measure sound intensity a special probe is used. The probe consists of two microphones mounted face-to-face separated by a solid spacer of known length. Based on the measured pressure gradient between the microphones and the average pressure, sound intensity is calculated. This two-microphone technique produces a vector that has magnitude and direction.

Before beginning the sound intensity measurement, the desired measurement surface was measured and divided into a grid consisting of rows and columns. The grid dimensions varied depending on the size of the measurement surface and the desired degree of frequency and spatial resolution. A 15-second measurement was taken 10-cm from the surface at each grid point using the intensity probe with a 12-mm spacer.

Figure 2. Sound intensity measurement.

Noise Dosimetry

To determine the amount of noise the machine operators were exposed to during the course of their day, noise dosimeters, also called noise dose meters, were used. The Quest Q-400 Noise Dosimeters used for exposure monitoring have two channels, referred to as dosimeter 1 and dosimeter 2, so two sets of noise exposure parameters can be measured simultaneously. Dosimeter 1 was set to monitor the Mine Safety and Health Administration's (MSHA's) Permissible Exposure Limit (PEL) of 90 dBA, and dosimeter 2 was set for wide range data collection. The settings for each dosimeter are shown in Table 1.

Dosimeter Number	Parameter	Settings	Designation
Dosimeter 1	Weighting Threshold Level Exchange Rate Criterion Level Response Upper Limit	A 90 dB 5 dB 90 dB Slow 140 dB	MSHA Permissible Exposure Limit
Dosimeter 2	Weighting Threshold Level Exchange Rate Criterion Level Response Upper Limit	A 40 dB 3 dB 85 dB Slow 140 dB	Wide Range

Table 1. Dosimeter settings.

For monitoring operator noise exposure the microphone was clipped to the shoulder of the equipment operator and worn for a full shift. To determine when and where the workers were receiving most of their noise dose, time-motion studies were performed.

In addition to monitoring worker exposure, dosimeters were used to monitor equipment sound levels. This method gives an indication of noise levels at a location on the machine, independent of operator movement. Figure 3 shows a dosimeter mounted in the cab of a face drill.

Figure 3. Dosimeter mounted for monitoring a face drill. The microphone is located just above the operator's ear.

RESULTS

The noise controls implemented on the drills and bolters were very consistent across the seven mines visited. All of the mines had implemented some, if not all, of the following controls: covers over the hydraulic motors; absorptive material in the canopy; absorptive material around the seat; absorptive material in the lower portion of the operator's area; and a windshield. Most of the controls were installed in such a way that allowed for removal and replacement by a trained mechanic with no degradation of performance.

Ten machines were tested, five roof bolters and five jumbo face drills. Since the noise reduction achieved by the installed controls is being evaluated rather than the machine itself, each machine will be referenced according to a generic identifier, e.g. Bolter 3. Also, it should be mentioned that these results are part of a larger study which measured and documented noise controls installed on most of the machines used in underground metal mining. The documented controls are a representation of how seven mine operators have attempted to reduce worker noise exposure and not an all-inclusive list of available technology.

Hydraulic Motor Covers

All of the tested drills and bolters were equipped with at least one hydraulic motor; the dual-boom face drills were equipped with two motors. The motors were located directly behind the operator area as shown in Figure 4. Five of the tested machines, two roof bolters and three jumbo drills, had engineering noise controls installed around the hydraulic motors. All of the reported measurements were made underground at the operator's ear position with only the hydraulic motors operating.

Table 2 shows the results from the noise controls used on the hydraulic motors. Bolter 1 had a motor cover constructed from ¼-inch heavy rubber conveyor belt, Bolter 2 had a cover constructed from 1.5-inch thick fiberglass blanket, Drill 1 had a motor cover constructed from

Figure 4. Dual boom jumbo face drill.

Figure 5. Heavy conveyor belt barrier, fiberglass blanket, and plexiglass motor covers

½-inch heavy rubber conveyor belt, Drill 2 had a cover constructed from 1.5-inch quilted fiberglass absorptive material, and Drill 3 had a motor cover constructed from ¼-inch plexiglass. Several of the tested controls are shown in Figure 5.

Motors	Uncontrolled Level dB(A)	Controlled Level dB(A)	Reduction dB(A)
Bolter 1	84.9	83.2	1.7
Bolter 2	77.3	76.9	0.4
Face Drill 1	79.4	77.2	2.2
Face Drill 2	79.9	79.5	0.4
Face Drill 3	84.3	81.9	2.4

Table 2. Noise reduction due to hydraulic motor noise controls

The results shown in Table 2 indicate that the motor covers constructed of a heavy barrier material, as opposed to an absorptive material, produce the most significant level reductions. However, it should be noted that the A-weighted sound levels created by the uncontrolled motors would produce a noise exposure below the Action Level of 85 dB(A), therefore noise control efforts should be directed elsewhere.

Absorptive Material in Canopy

Most of the machines tested had sound absorbing material under the canopy. However, only three of the machines had the material installed in such a way that it could be removed and easily replaced to directly measure the noise reduction attributable to it as a control. In all of the reported cases the absorptive material was a 1-inch thick quilted fiberglass blanket. Figure 6 shows the material being removed for testing.

Table 3 shows the noise reduction achieved due to the absorptive material applied to the canopy. The Face Drill results were acquired underground during the drilling cycle, while the Bolter results were measured above ground with the percussive hammer operating. All measurements were performed at the operator's ear location.

Figure 6. 1-inch thick quilted fiberglass blanket being removed for testing

Canopy	Uncontrolled Level dB(A)	Controlled Level dB(A)	Reduction dB(A)
Bolter 2	97.4	97.3	0.1
Face Drill 1	99.1	99.3	-0.2
Face Drill 2	99.6	99.6	0
Face Drill 2 *(no windshield)*	100.3	100.1	0.2

Table 3. Noise reduction due to absorptive material in canopy

Face Drill 2 had a movable windshield so the effect of the absorptive material in the canopy was measured with and without (no windshield) the windshield. The other reported results are with the windshield in place. In all cases, the results shown in Table 3 indicate that absorption placed in the canopy has a minimal to no effect on the sound levels that the operator experiences.

Absorptive Material Around Operator Area

One tested bolter and one tested face drill had a 1-inch thick quilted fiberglass blanket around the operator's area that could be removed for testing. To determine what effect the material had on the sound level reaching the operator's ear, measurements were performed underground with the windshield in place while Bolter 1 was drilling and bolting. The operator's area of Bolter 1 is shown in Figure 7. On Face Drill 2 the sound level reduction attributable to the material was measured while only the hydraulic motors were operating.

Table 4 shows the results from the absorptive material placed around the operator.

Seat Absorption	Uncontrolled Level dB(A)	Controlled Level dB(A)	Reduction dB(A)
Bolter 1 (drilling)	97.5	97.6	-0.1
Bolter 1 (bolting)	98.4	98.7	-0.3
Face Drill 2 (motor)	78.1	77.2	0.9

Table 4 Noise reduction due to absorptive material around operator

The results shown in Table 4 indicate that the absorption around the seat has essentially no affect on the sound level during the drilling process. During the bolting process the measured sound level at the operator's ear was actually 0.3 dB(A) higher with the material in place. However, this difference is so small that it would have a negligible affect on the noise exposure of the operator.

When only the hydraulic motor is in operation a reduction of nearly 1 dB(A) was achieved. This reduction occurred because the material around the operator area on Face Drill 2 was located between the motor, which was the noise source, and the operator.

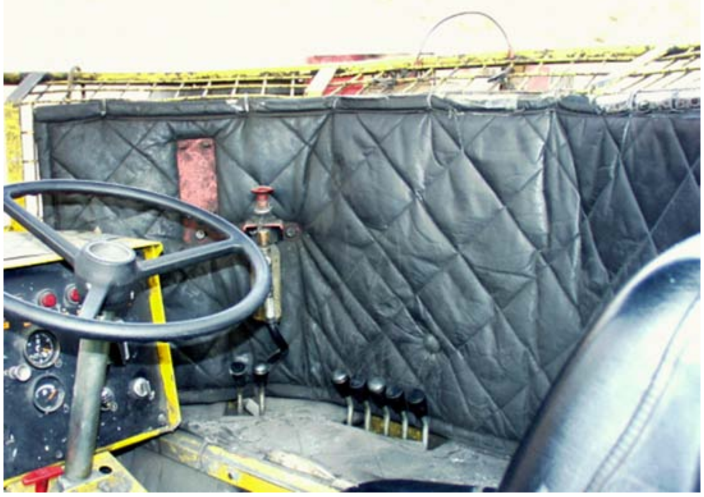

Figure 7. Quilted fiberglass material in the operator's area of Bolter 1.

Absorptive Material in Lower Front of Cab

Figure 8 shows 1-inch thick quilted fiberglass blanket applied to the lower front of the operator area on Bolter 2. This material is located where the operator's knees would be positioned while operating the drill boom.

Table 5 shows the effect the absorptive material placed in the lower front of the operator cab had on sound levels measured at the operator's ear during drilling and bolting.

Figure 8. Quilted fiberglass material in the lower front of the operator's area of Bolter 2.

Lower Cab Absorption	Uncontrolled Level dB(A)	Controlled Level dB(A)	Reduction dB(A)
Bolter 2 (drilling)	98.1	97.9	0.2
Bolter 2 (bolting)	99.9	99.9	0

Table 5a. Noise reduction due to absorption placed in lower front of cab with windshield.

Lower Cab Absorption	Uncontrolled Level dB(A)	Controlled Level dB(A)	Reduction dB(A)
Bolter 2 (drilling)	98.5	98.5	0
Bolter 2 (bolting)	101.5	101.2	0.3

Table 5b Noise reduction due to absorption placed in lower front of cab without windshield

The results indicate that absorptive material placed in the lower portion of the operator cab has essentially no effect on the sound levels that the operator experiences.

Windshields

The most common engineering noise control installed on the tested drills and bolters was a windshield. The amount of noise attenuation achieved varied greatly depending on how the windshield was designed and installed. Several examples of windshields are shown in Figure 9.

Figure 9. The windshields installed on Bolter 2, Bolter 3, and Bolter 5 respectively.

Most of the windshields were designed to be flipped up into the canopy. This feature allowed the operator an unobstructed view while tramming the machine and it also allowed for sound levels to be measured at the operator position with the windshield in place and with it not in place. Table 6 shows the effect that the tested windshields had on sound levels reaching the operator's ear underground.

Windshields	Uncontrolled Level dB(A)	Controlled Level dB(A)	Reduction dB(A)
Bolter 2 (Drilling)	98.5	97.9	0.6
Bolter 2 (Bolting)	101.2	99.9	1.3
Bolter 5 (Drilling)	100.6	99	1.6
Bolter 3 (Drilling)	99.2	96	3.2
Bolter 3 (Bolting)	105.7	102.5	3.2
Face Drill 1	101.7	99.3	2.4
Face Drill 2	100.3	99.6	0.7
Face Drill 3	97.1	95.3	1.8
Face Drill 4 (single boom)	94	91.9	2.1
Face Drill 4 (dual boom)	98.9	95.6	3.3
Face Drill 5	101.9	100.6	1.3

Table 6 Noise reduction due to windshields

The results indicate that a windshield designed so that gaps, or flanking paths, are minimized, will reduce sound levels at the operator's ear more so than a windshield designed to have a gap between panes of glass.

DISCUSSION

The application of fiberglass absorptive material to the canopy, seat area, and lower portion of the cab had little to no effect on the sound level at the operator's ear during the drilling and bolting process. To reduce the sound level reaching the operator, sound absorbing materials must be placed on surfaces that reflect sound towards the operator's hearing zone. In an open cab, such as those installed on the face drills and roof bolters tested, absorptive materials will be of limited benefit.

The well designed windshields, in general, were the most consistent noise control implemented on the drills and bolters. This is because the windshields form a barrier between the noise source, which is the drilling and bolting process, and the operator. Also, the noise generated by drilling and bolting is predominantly high frequency in content. High frequencies are easier to block and absorb due to their shorter wavelength. The windshields that were designed with a space between an upper and a lower pane of glass did not reduce the sound levels reaching the operator as much as the solid windshields. This is because the gap allows sound energy to "leak" through to the operator.

On Bolter 5 an attempt was made to supplement the windshield with an operator enclosure constructed from conveyor belt strips. This can be seen on the far right in Figure 9. Unfortunately, due to the gaps in-between the strips, the conveyor belting had no effect on the sound levels reaching the operator's ear.

CONCLUSIONS

In summary, when applying noise control treatments, care should be taken to use the right product for the job. The ½-inch rubber conveyor belt mats and the ¼-inch plexiglass motor covers reduced motor noise because these are barrier materials, which is the correct choice for the application. The motor controls used on Bolter 2 were sound absorbers that had almost no effect on the noise output from the motors. Sound absorbing material is much more effective when backed by a noise barrier. However, hydraulic motor covers on the tested face drills and roof bolters are not necessary as the noise levels produced by the uncovered motors are below 85 dB(A), much lower than the levels produced by other noise generating mechanisms to which the operator will be exposed.

The use of absorptive materials in the operator's area slightly reduces sound levels underground on the machines tested. Due to the operating environment and the openness of the operator area a large reduction in noise levels from this control is not expected.

The windshields reduced the noise reaching the operator during the drilling/bolting cycle. The generated noise from the aforementioned processes is relatively high frequency in content therefore the windshield provides a protective barrier between the noise source and the operator. Care should be taken to seal gaps in the windshield and between the windshield and the structure of the machine.

In the future, this project will evaluate noise controls used in other mining sectors, as well as revisit the underground metal sector as new noise controls are implemented.

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