MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Development and field evaluation of noise controls for jumbo drills

Camargo, Hugo[1]
Peterson, Shawn
Kim, Brian
Alcorn, Lynn
National Institute for Occupational Safety and Health
Centers for Disease Control and Prevention
626 Cochrans Mill Road
Pittsburgh, PA 15236

ABSTRACT

Despite over thirty years of regulation on noise exposure, hearing loss continues to be one of the most prevalent illnesses in the mining industry in the United States. One machine used extensively in metal/nonmetal mines responsible for high noise exposure of its operators is the jumbo drill, used to drill holes at the mines for blasting purposes. In this context, the National Institute for Occupational Safety and Health (NIOSH) conducted research to develop noise controls for these machines. Noise source identification showed that the vibration of the drill string is the dominant source. Therefore, two different approaches were taken to reduce drill string sound radiation: vibration isolation and the addition of damping. This paper presents the development and the results of laboratory and field testing of damped drill strings by comparing the operator location sound levels when drilling with a standard drill string to the sound levels when drilling with the noise controls installed. The paper also provides a discussion of the various design parameters, including the material property selection, the dimensional constraints, and durability issues. Furthermore, the results of the field evaluation of these noise controls--in terms of noise reduction at the operator's location and drilling performance--are presented. Overall, a 3 to 5 dB reduction at the operator location was achieved with these noise controls.

Keywords: Noise, Mining, Engineering Controls
I-INCE Classification of Subject Number: 30

1. INTRODUCTION

Noise-induced hearing loss (NIHL) continues to be one of the most prevalent diseases in the mining industry in the United States. According to a recent study conducted by the National Institute for Occupational Safety and Health (NIOSH), in which over one million audiograms from various industries were analyzed, the mining industry exhibits the highest prevalence of hearing loss of all industries surveyed [1].

---

[1]HCamargo@cdc.gov

The mining sector has the highest prevalence of hazardous workplace noise exposures (76%) among all industrial sectors [2]. Therefore, despite over 30 years of regulation and various engineering and administrative controls implemented to reduce noise, miners continue to exhibit a high prevalence (24%) of hearing loss [3].

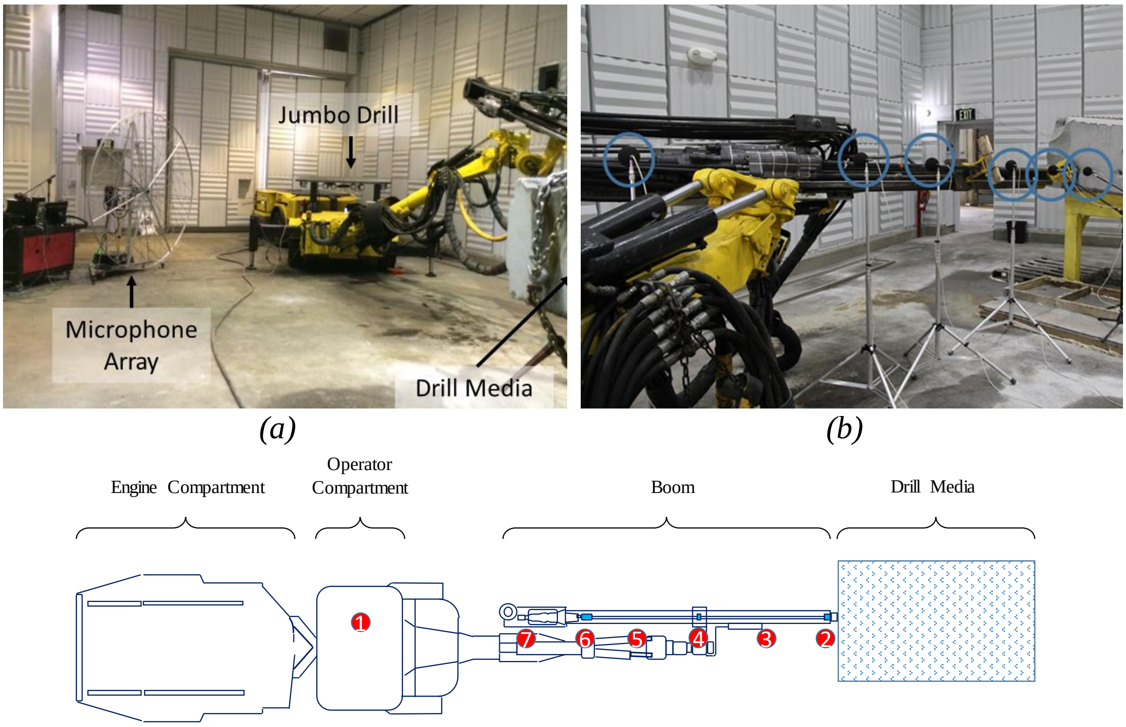
In this context, NIOSH conducted research to develop noise controls for jumbo drill machines. These machines are used in underground metal/nonmetal mines to drill holes for blasting purposes. Operators of jumbo drills are exposed to high sound levels that frequently result in a hazardous noise dose, which creates an elevated risk of NIHL. The Mine Safety and Health Administration (MSHA), NIOSH, and the former U.S. Bureau of Mines (USBM) have all documented occurrences of noise overexposure to jumbo drill operators [4].

During the first stage of this research, NIOSH used time-motion studies and dosimetry to evaluate a dual-boom jumbo drill operator’s exposure to noise. A dual-boom is a jumbo drill equipped with two separate drilling mechanisms. When drilling with a single boom, the operator was exposed to an average sound level of 103–104 dB(A). When drilling with both booms simultaneously, the sound level increased to 105 dB(A). With these exposure levels, the operator would receive a hazardous noise dose within 5 minutes of active drilling, based on the NIOSH recommended exposure limit (REL) of 85 dB for an 8-hour time-weighted average (TWA). NIOSH also conducted time-motion and dosimetry studies, which indicated that the jumbo drill operator is exposed to levels exceeding the MSHA permissible exposure level (PEL) of 90 dB(A) and accumulates a large portion of the noise dose during the drilling activity. Also, during the course of this research, noise source identification efforts conducted using microphone-phased array technology showed several noise sources during the drilling process. These sources included the bit-rock interaction, the front end of the drill string, the coupler, and the actual drilling mechanism, i.e. the drifter [5]. The drill string is a long hollow rod that connects to the drilling mechanism—which provides rotation and percussion—in one end, and to the drill bit in the other end. Then, using a transfer path analysis technique, these noise sources were ranked based on their contribution to the noise levels at the operator’s location. From this analysis, it was determined that the vibration of the drill string is the dominant sound-generating mechanism that contributes the most to the operator’s noise dose accumulation [6].

Today, jumbo drill operators are still being exposed to excessive noise levels in the mining environment. With modern advances in technology, these machines have become larger and more powerful. These changes lead to increased noise exposure to the operator and others working in the relatively confined spaces where these machines are typically used. Prior research has indicated that the drill string radiates a significant portion of the noise during drilling [5, 6]. To address this problem, this paper presents proof-of-concept validations in terms of noise reduction using a noise control concept based on increasing damping to the drill string to reduce its surface vibration and thus its sound radiation.

2. EXPERIMENTAL SETUP

Three sets of tests were conducted by NIOSH researchers to evaluate the noise reduction performance of the damped drill string concept. The first set of tests was conducted at NIOSH’s hemi-anechoic chamber. The machine used for this set of tests was an Atlas Copco Boomer S1L jumbo drill machine. The drill media was granite with a compressive strength of approximately 24,000 psi. Figure 1 shows a photo of the experimental setup for these tests.



(c)

Figure 1. *Experimental setup for testing at NIOSH's hemi-anechoic chamber: (a) Front-view of the jumbo drill, (b) location of the microphones (in blue circles) used for the tests, and (c) location of microphones in relation to identified noise sources.*

During these tests, three holes were drilled with each drill string. Each hole had a depth of 60 inches and took approximately 60 seconds to complete. Time data were sampled by seven microphones placed in different locations along the boom and at the operator's location, as shown in Figure 1b. These locations, shown in Figure 1c, represent each noise source identified during the initial stage of the project [6].

The other two sets of tests were conducted at collaborating mines designated as Mine A and Mine B. The jumbo drill at Mine A was a single-boom, while Mine B had a dual-boom jumbo drill machine, as shown in Figure 2.

(a) *(b)*

Figure 2. *Field test setup used in (a) Mine A (single-boom), and (b) Mine B (dual-boom).*

At Mine A, 10 holes were drilled with the standard drill string (baseline), and 28 holes were drill using the constrained layer damped (CLD) drill string. All holes at this mine were approximately 3 meters deep. At Mine B, 23 holes were drilled with the standard drill string (baseline), 28 holes using the CLD drill string (60A durometer) on the left boom, and 30 holes using the CLD drill string (40A durometer) on the right boom. All holes at this mine were approximately 5 meters deep.

The drill string used by Mine A was 3.089 meters long with an outside diameter of 0.032 meters (121.625-inches long and 1.25-inches outside diameter). Mine B used a drill string 5.486 meters long with an outside diameter of 0.032 meters (18-feet long drill and 1.25-inch outside diameter). For data collection during the field tests, Larson Davis Spark 705 personal dosimeters were used at the operator's location. If the machine was provided with a cab, as was the case for Mine B, the dosimeters were mounted immediately outside the cab. These mounting locations were selected because sound measurements inside the cab would not be an accurate representation of the acoustic performance of the controls in terms of noise reduction at the operator's location.

3. NOISE CONTROL SPECIFICATIONS

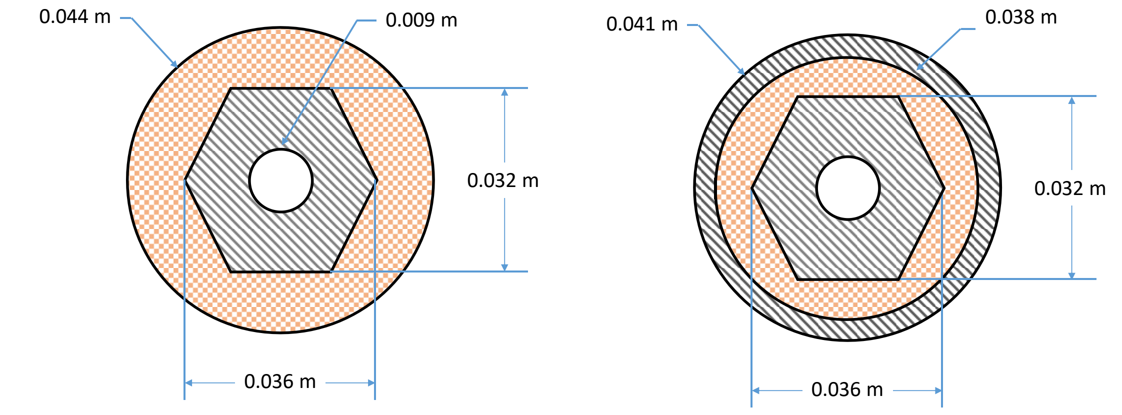
3.1 Noise Controls for Laboratory Tests

The objective of this test was to conduct a proof-of-concept test in a controlled laboratory environment to determine the viability of reducing noise emissions by using a damped drill string. Hexagonal drill strings 3.09 m long, 35.8-mm from vertex to vertex in the cross section, were used for this set of tests. Two of these drill strings were coated with a 93A durometer Volkalin layer so that the drill string's round outer diameter was increased to 46.7 mm including the coating. The 93A durometer Volkalin was chosen because it was expected that the abrasive nature of drilling into granite would require a rugged material to survive. One drill string was coated half of its length at the bit end, while the other was coated half of its length at the drifter end. They were only coated halfway due to limitations in the coating process. An uncoated drill string was used for baseline measurements, as shown in Figure 3. To accommodate the increased outer diameter of the damped drill strings, all tests were conducted with 76-mm-diameter drill bits.

Figure 3. *Drill strings used for laboratory testing: coated at the drifter end (top), coated at the bit end (middle), and a stock drill (bottom) used for baseline testing.*

3.2 Noise Controls for Mine A

For the second set of tests, conducted at Mine A, two 3.09-m-long, 35.8-mm cross section, hexagonal drill strings were used. One of these drill strings was coated with a 70A durometer Volkalin (Plei-Tech 15, PT-15) layer. The other drill string was covered with a 70A durometer Methylene diphenyl diisocyanate (MDI) (Plei-Tech 22, PT-22) material and encompassed by a round steel tube, using the concept of constrained layer damping. The stock drill string used by the mine (3.21-m long and a 35.8-mm section) served for the baseline noise emission testing. Figure 4 shows the cross-section dimensions of these damped drill strings.



(a) *(b)*

Figure 4. *Cross-section dimensions of the (a) damped drill string and the (b) constrained layer damped drill string used at Mine A.*

3.3 Noise Controls for Mine B

For the third set of tests, conducted at Mine B, 5.53-m long, 35.8-mm cross section, hexagonal drill strings were used. These were the stock drill strings typically used by this mine. During these tests, two constrained layer damped drill strings were evaluated. The first of these drill strings was coated with a (PT-15) 60A durometer Volkalin and the second with a (PT-22) 40A MDI material. Both were encompassed by circular stainless steel tubing—with dimensions shown in Figure 5—to serve as the constraining layer for the Volkalin or MDI.

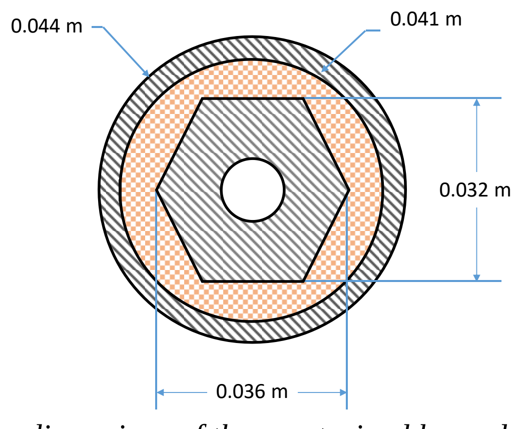


Figure 5. *Cross-section dimensions of the constrained layer damped drill string used at Mine B.*

4. RESULTS AND DISCUSSION

The first set of damped drill strings tested in a laboratory environment provided a modest noise reduction of approximately 1.5 dB. Figure 6 shows the sound pressure level, moving average, at the operator's location. From this figure, it can be seen that the damped drill string coated at the bit end has the best performance in terms of noise reduction.

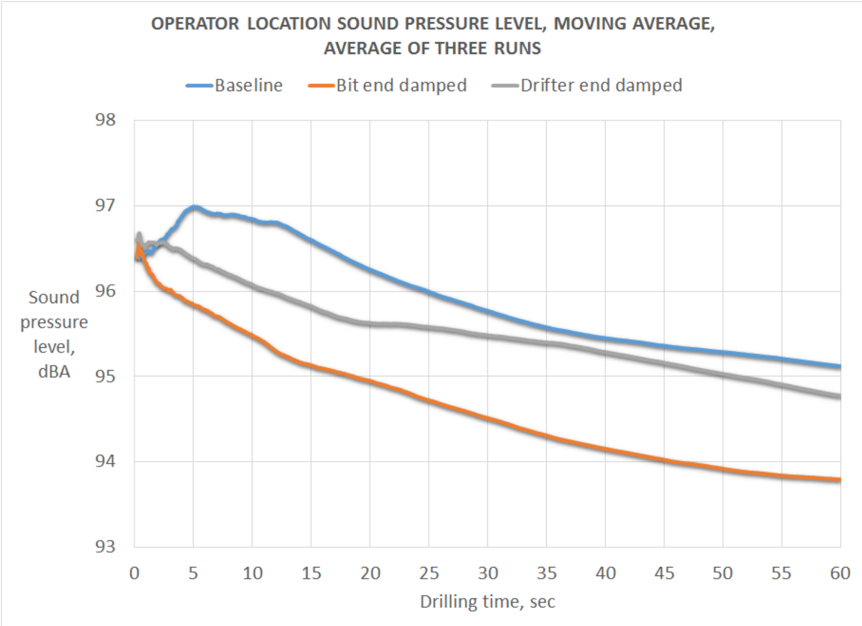
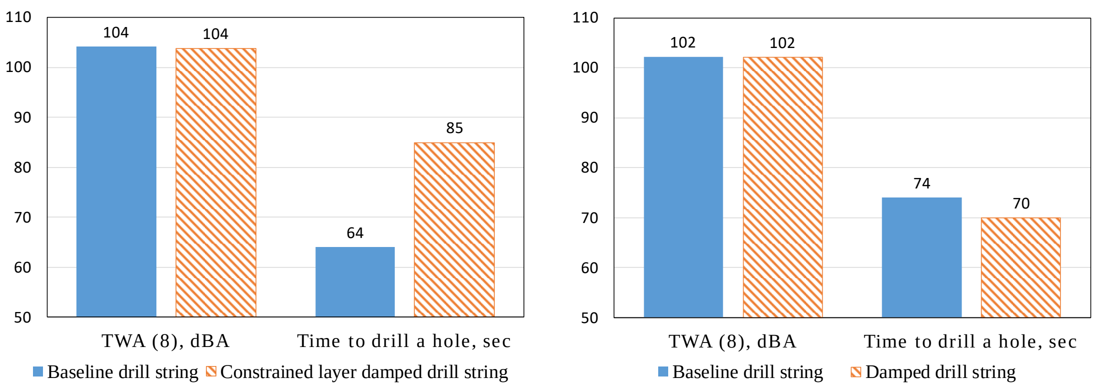


Figure 6. *Sound pressure level at the operator location for the set of damped drill strings tested in a laboratory setting.*

The results from the second set of tests (at Mine A) did not yield noise reduction at the operator's location. These results can be seen in Figure 7. From this figure, it can also be noted that in terms of drilling performance, using the constrained layer damped drill string resulted in a slower penetration rate, since it took approximately 33% longer to complete the holes.



(a) *(b)*

Figure 7. *Field test results for Mine A: (a) damped drill string coated with 79A Volkalin and (b) constrained layer damped drill string with 70A durometer MDI layer.*

The third set of results (at Mine B) yielded significant noise reduction, especially when the drill string was coated with a PT-22 40A durometer layer and an additional outer steel tube was used as the constraining layer. As shown in Figure 8, drilling with this constrained layer damped drill string yielded a reduction of above 5 dB at the operator's location. However, drilling with the PT-15 60A durometer constrained layer damped drill string yielded a 2.5 dB reduction.

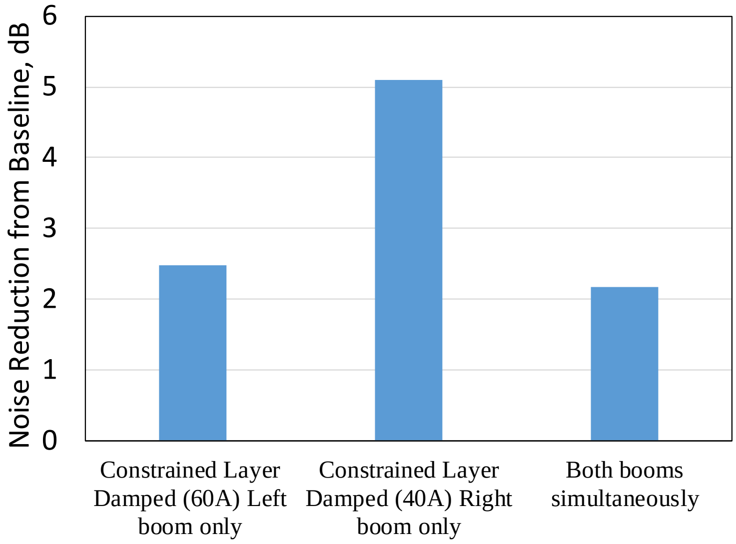


Figure 8. *Field test results for Mine B.*

One of the main challenges during the development of the various damped drill strings was the limited margin to increase or change the dimensions—i.e. the outer diameter—of the drill string. To adjust for the increase in outer diameter caused by the damping material layer and to evaluate the performance in terms of noise reduction, a larger-diameter bit was used during the laboratory tests. However, using a larger-diameter bit is not always an option in all mines.

Another challenge with this noise control concept is the durability of the coating. To keep the drill string aligned and to prevent it from bowing, there is a guide located mid-way of the drill string; this guide, shown in Figure 9 and referred to as the centralizer, is usually in contact with the rotating drill string, which will eventually result in the wear of the damping material. Under some circumstances, there is also rubbing contact between the drill string and the rock, which would also result in the wear of the damping material.

Figure 9. *Location of the centralizer along the boom of the jumbo drill machine.*

In terms of coating only a partial segment of the drill string, the results from the lab tests showed that coating the bit-end half of the drill string yielded more noise reduction than coating the drifter-end half. These results are consistent with the noise source identification findings, which showed that most of the sound is radiated by the front half (i.e. the half towards the bit end) of the drill string.

Regarding the damping material and damping approach, the best results were obtained with the constrained layer damping approach using PT-22 material, which has a 40A durometer hardness. Higher-durometer materials, which provide less damping, resulted in modest to no noise reduction.

5. CONCLUSIONS

The results presented in this paper constitute a set of initial proof-of-concept validations for a noise control for jumbo drill machines. Different types of coating material, length of coating, and damping approaches were tested experimentally. The best results in terms of noise reduction were obtained by using a constrained layer damped drill string with a PT-22 40A durometer layer. These tests also showed that fine-tuning the damping material properties and the dimensions of the damping layers has the potential of yielding higher noise reduction. The next step in the validation process of these noise controls will involve evaluation of the durability of the damping and constraining layers under normal operating conditions

Test results from Mine A suggest that using a constrained layer damping approach increased drilling time. Test results from Mine B suggest that drilling noise can be reduced when using a slightly different constrained layer damping approach. Given an actual mining production scenario where a jumbo drill operator would be exposed to lower noise levels but for longer periods of time, their noise exposure would likely change in comparison to the noise exposure measured during the field tests. Therefore, additional studies quantifying these changes would be beneficial, using data collected at collaborating mines using baseline and NIOSH-developed drill strings.

Disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

6. REFERENCES

1. E.A. Masterson, S. Tak, C.L. Themann, D.K. Wall, M.R. Groenwold, J.A. Deddens, G.M Calvert, “Prevalence of Hearing Loss in the United States by Industry,” *American Journal of Industrial Medicine, 56(6), pp 670-681. Doi: 10.1002/ajim.22082, (2012)*
2. S. Tak, and G. Calvert, “Hearing Difficulty Attributable to Employment by Industry and Occupations: An Analysis of the National Health Interview Survey—United States, 1997–2003,” *Journal of Occupational and Environmental Medicine*, 50, pp. 46–56, (2008)
3. S. Tak, R.R. Davis, G. Calvert, “Exposure to Hazardous Workplace Noise and Use of Hearing Protection Devices among U.S. Workers—NHANES, 1999–2004,” *American Journal of Industrial Medicine*, 52, pp. 358-371, (2009)
4. E.R. Spencer, “Assessment of Equipment Operator’s Noise Exposure in Western Underground Gold and Silver Mines,” *SME Preprint* 09-073, (2009)
5. J.S. Peterson, H.E. Camargo, M. Li, “Beamforming and Coherence Analysis of a Single-Boom Jumbo Drill,” *Internoise 2015, San Francisco, CA, USA*, August (2015).
6. H.E. Camargo, J.S. Peterson, and B. Kim, “Application of Transfer Path Analysis Techniques to Determine Noise Source Contribution in Mining Equipment,” *Proceedings of NoiseCon 2017*, Grand Rapids, MI, June 12-14, (2017).