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Laboratory Noise Testing of a Jumbo Drill

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ABSTRACT
There is a high prevalence of hazardous noise exposures among the nation's mining workforce, with 76% of miners overexposed to noise and 27% suffering from noise-induced hearing loss. Field time-motion and dosimeter studies have revealed that jumbo drill operators are frequently overexposed to noise and may be subjected to noise levels exceeding 100 dB(A). To address these problems, NIOSH initiated a research project seeking to develop noise controls to reduce the sound level at the jumbo drill operator's location and thus reduce the operator's noise exposure. Key to the success of this effort is determining the primary noise sources on a jumbo drill. Earlier project research included noise source identification testing using beamforming techniques in the field. This paper discusses similar beamforming testing conducted on a single-boom jumbo drill in an acoustical laboratory environment. This testing revealed primary noises along the drill string and also at the drifter. Additional testing documented the effect of drill bit diameter on the sound power emitted by the jumbo drill during drilling.

1 INTRODUCTION
Jumbo drill operators are exposed to high sound levels that frequently result in a hazardous noise dose and create an elevated risk of noise-induced hearing loss (NIHL). The Mine Safety and Health Administration (MSHA), the National Institute for Occupational Safety and Health (NIOSH), and the former U.S. Bureau of Mines (USBM) have all documented occurrences of noise overexposure for the operators of rotary-percussive jumbo drills.[1] A recent field study conducted by the Workplace Health Branch (WHB) of the Pittsburgh Mining Research Division (PMRD) used a time-motion and dosimetry method to evaluate a jumbo drill operator's exposure to hazardous noise. During drilling, the sound level at the jumbo drill operator location can sometimes exceed 105 dB(A). Given the MSHA Permissible Exposure Level (PEL) of an 8-hour time-weighted

average of 90 dB(A), an operator could drill continuously for only an hour before becoming over-exposed to noise. At this same sound level of 105 dB(A), an operator would receive a hazardous noise dose after drilling for only 7 ½ minutes, based on the NIOSH recommended exposure limit (REL). To address this problem, NIOSH PMRD has initiated a noise control research project with the objective to develop noise controls that reduce jumbo drill operator noise exposure by at least 3 dB(A) and to facilitate mining industry usage of these noise controls.

When NIOSH conducted its time-motion and dosimetry studies of jumbo drill operators, the jumbo drill duty was broken down into tasks of drilling, not drilling, and tramming. The studies indicated that the jumbo drill operator is exposed to the highest noise levels and accumulated a large portion of their noise dose during drilling.[2] Additional NIOSH field testing on a Canon single-boom DP12 jumbo drill suggested that the drill string was a significant source of the sound level at the drill operator's position.[2] It was deemed necessary to conduct similar testing on an additional jumbo drill to determine its primary noise sources. In this case, NIOSH conducted the testing in a controlled acoustic environment at its laboratory facilities in Pittsburgh, PA. The WHB maintains an Acoustic Test Chamber (ATC), a reverberation chamber in which sound power level testing is conducted.[3] Additionally, the Branch maintains a hemi-anechoic chamber (HAC) in which NIOSH can conduct noise source identification testing, e.g., beamforming, as well as sound power testing should the need arise. NIOSH conducted sound power tests on a single-boom Sandvik DD210 jumbo drill in the ATC to determine baseline sound power emissions of the drilling noise. Additionally, NIOSH evaluated a variety of drill bit diameters to quantify their effect on the noise emission. In the HAC, the Branch conducted beamforming testing during drilling and also conducted proof of concept testing to verify that addressing the prominent noise sources identified by the beamforming testing could lead to viable jumbo drill noise controls in the future.

2 EXPERIMENTAL DESIGN

2.1 Sound power testing

Key to the development of noise controls is to determine a baseline noise emission for the equipment under investigation. Later, after the development and implementation of the noise controls, the sound power tests would be repeated and the results compared to the baseline data collected earlier. In its ATC, NIOSH conducts sound power testing meeting requirements of an engineering-grade acoustics standard ISO 3743-2[4] and a precision-grade acoustics standard, ANSI S12.51/ISO 3741.[5] For this study, NIOSH conducted a series of sound power tests, determining the sound power emitted during drilling into blocks mounted on a support stand in the ATC (Figures 1 and 2). To mimic a hard mine face, NIOSH used granite with a compressive strength of 166 MPA for the drilling block material. Sandvik button-type bits (Figure 3) were mounted on a 4,305 mm Sandvik drill string for this testing. A variety of drill bit diameters were utilized during the testing: 51, 64, and 76 mm.

Figure 1 *: Jumbo drill during sound power testing.*

Figure 2 *: Close-up view of drilling into a granite block.*

Figure 3 *: Examples of the drill bits used during sound power testing*

2.2 Beamforming

NIOSH collected beamforming data in its HAC using a Bruel & Kjaer Pulse data acquisition system, 84-microphone array, and Pulse beamforming application software. For each drilled hole, beamforming data was collected three times while the jumbo drill operator drilled to the full hole depth of 1,500 mm. Multiple holes were drilled in this manner. Data was then processed using a delay-and-sum beamforming algorithm and the results were obtained in the form of one-third octave band acoustic maps, showing the location of the dominant noise sources.

2.3 Proof of concept testing

This testing was also conducted in the HAC using a Bruel & Kjaer Pulse system for data acquisition. Proof of concept testing is conducted early in the noise control development process. Here, simple noise controls are tested to ensure that the research is following a viable path in pursuing controls to address a particular noise source. These noise controls do not have to be durable, as they only have to survive for the duration of the testing. They do not have to be practical, as they are tested only to ensure the research direction shows promise in reducing noise emissions. Should the proof of concept testing show a worthwhile reduction in the sound level at the operator location, then more durable and practical controls would be investigated.

3 RESULTS AND DISCUSSION

3.1 Sound power testing

Sound power testing results are summarized below in Figure 4. This data serves to quantify the noise emission for baseline data purposes and to illustrate the influence of drill bit diameter on the sound power. Increasing the bit diameter does have an effect on the sound power emission as it increases linearly when drilling with 51, 64 and 76 mm drill bits. One-third octave band sound power results are shown in Figure 5. Of importance are the 2,500, 3,150, and 4,000 Hz one-third octave bands. These are the dominant one-third octave band frequencies for this testing. Prospective noise controls to reduce jumbo drill operator location sound levels, and thus, noise exposure, must address noise in these frequency bands.

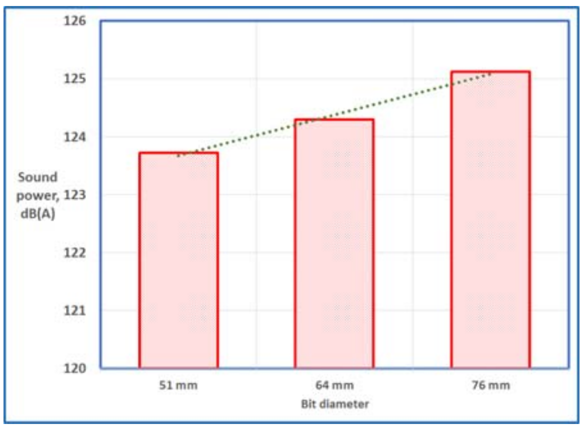

Figure 4 *: The sound power emission, when drilling with 51, 64, and 76 mm drill bits, increases linearly.*

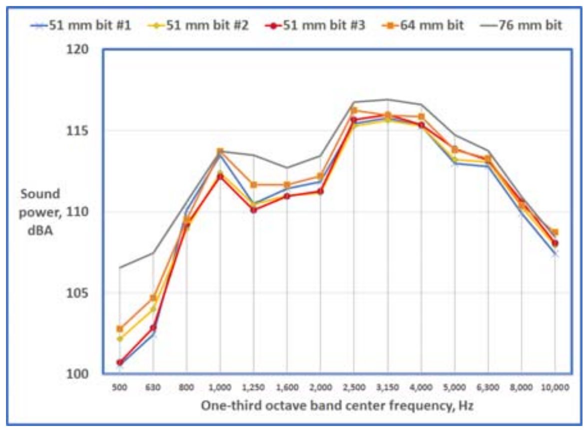

Figure 5 *: One-third octave band sound power for all drill bits under test peak in the 2,500-4,000 Hz bands.*

3.2 Beamforming

NIOSH conducted a series of beamforming tests for noise source identification purposes. Representative illustrations of the results are shown below in Figures 6 and 7. In Figure 6, the beamforming data was collected early in the drilling process, just after the drill bit was fully collared inside the rock. For Figure 7, beamforming data was collected after the bit had advanced further into the granite, near its full depth of roughly 1,500 mm. The results show multiple noise sources, one being at the drifter location. The drifter radiates significant noise and is also close to the operator. There were one or two (depending the bit depth) other sources along the drill string, near the rock interface. These were the drill string vibrating and radiating noise. The source locations change at the bit advances into the drilling block, similar to results documented during the testing of the Canon jumbo drill mentioned earlier.[2] The drill string guides (Figure 8) on the Sandvik machine tested here were made of steel and were not considered a noise source. But, it was thought that during drilling, the drill string impacts the guides, creating impact noise and also mechanically exciting the drill string, causing it to vibrate and radiate noise.

Figure 6 *: Beamforming data collected just after the drill bit was fully collared, 2,500 Hz one-third octave band.*

Figure 7 *: Beamforming data collected near the end of the full hole depth, 2,500 Hz one-third octave band.*

Figure 8 *: Location of drill string guides.*

3.3 Proof of concept testing

To address the drifter noise source, NIOSH draped acoustic blankets over the drifter and collected operator location sound level data during drilling. To more fully enclose the drifter, NIOSH then added acoustic blankets over the hose reel and repeated the testing (Figure 9).

Figure 9 *: View showing acoustic blankets draped over the drifter and hydraulic hose reel.*

To address the drill strings source(s), NIOSH fabricated two sets of drill string inserts as replacements for the two steel guides (Figure 11). The first set of inserts were fabricated from Ultra High Molecular Weight Polyethylene (UHMW-PE) plastic and the second set from Delrin® acetal homopolymer. Again, sound pressure level data were collected at the operator location during drilling. To complete the testing, NIOSH conducted measurements with the Delrin® drill string guides and acoustic blankets in combination.

Figure 10 *: Guide inserts used for proof of concept testing, made of UHMW-PE on the left (Insert #1), and Delrin® on the right (Insert #2).*

Figure 11 shows the results of the testing. Given baseline conditions, the sound pressure level at the operator location was 102 dBA. Sound power data collected in the ATC showed that the sound power was at its maximum in the 2,500, 3,150 and 4,000 Hz bands, Here, the baseline sound pressure level was at its maximum in the 2,500 Hz one-third octave band frequency. Draping the blankets over the drifter and then also over the hydraulic hose reel resulted in 3 and 4 dB reduction, respectively, in the overall sound pressure level at the operator location. Implementing either set of guide inserts alone resulted in a reduction of 2 dB at the operator location. When applying the blankets and guide inserts in combination, the reduction remained at 4 dB at the operator location. Implementing the blankets and guide inserts reduced the operator location sound level at 2,000 Hz and above, with a large 6 dB reduction in the 2,500 Hz band.

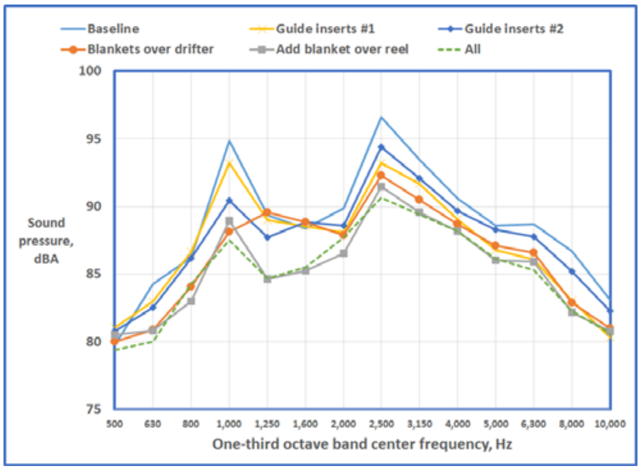

Figure 11 *: Graph showing that implementing guide inserts or using a barrier material over the drifter reduces the sound pressure level at the operator location.*

4 CONCLUSIONS

The sound power data based on this testing suggest that increasing the drill bit diameter would result in an increased sound power emission. Further, this serves as baseline noise emission data for the drill under test. Beamforming results show that the drifter is a noise source for the sound level at the operator location and warrants further investigation. A second source, the drill string, was also revealed by the beamforming testing. This is in agreement with prior NIOSH research[2] and also Hawkes and Burks,[6] Beiers,[7] and Ogren.[8]

Proof of concept testing illustrated that addressing these two noise sources could have a positive effect on reducing the sound level at the operator location. This, in turn, would reduce the operator noise exposure and susceptibility to NIHL. Shown in Figure 12 is jumbo drill operator noise exposure data collected at a collaborating mine. Dosimetry and time-motion data was collected for four operators, and an 8-hour noise exposure was calculated for each. These noise exposures ranged from 91 dB(A) to 104 dB(A). The wide range of the noise exposures can attributable to several factors. Examples of these factors are, the number of holes drilled by the operator, the compressive strength of the face being drilled, or the skill of the operator.

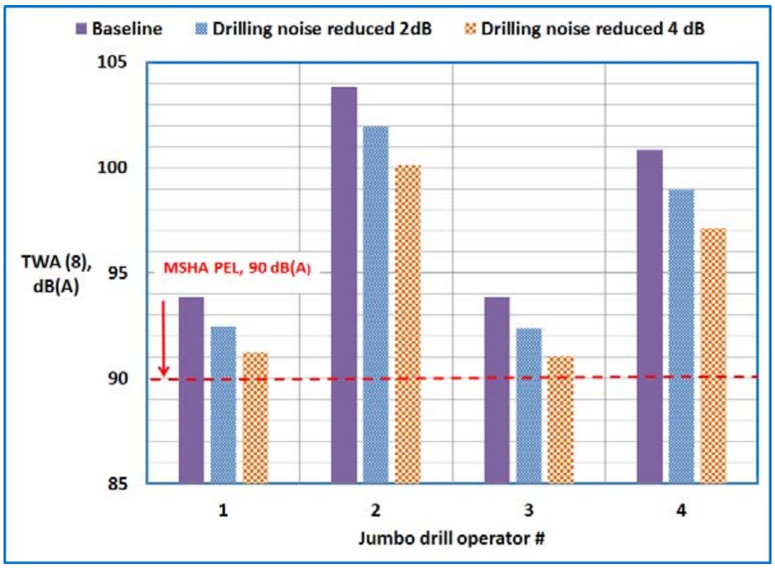

***Figure 12** : Reducing drilling noise will reduce an operator's 8-hour noise exposure.*

Also shown in Figure 12 is the noise exposure, given a reduction in drilling noise of 2 and 4 dB, per the proof of concept testing. Here, it is assumed that all other noise is the same—i.e., noise during tramming, maintenance, etc., is unchanged. Reducing the first and third operators drilling noise by 4 dB would reduce their noise exposure to roughly 91 dB(A), almost to within compliance per the MSHA PEL. Reducing the drilling noise would also have a significant reduction in the noise exposure of operators #2 and #4, from 104 dB(A) to 100 dB(A) and from 101 dB(A) to 97 dB(A) respectively. These operators would not be within compliance but could drill for a longer period of time before reaching the MSHA PEL.

Additional testing shall be conducted to address jumbo drill operator noise exposure. The drifter and the drill string will be more fully investigated. Sources within the drifter, e.g., the percussive hammer, are expected to result in excessive vibration of the drill string.[2] It is expected that bending waves within the drill string induce vibration, and thus noise. Bending and stress waves within the drill string shall also be studied.

5 REFERENCES

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