Noise and vibration assessment of a roof bolting machine

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In its 1996 National Occupational Research Agenda, the National Institute of Occupational Safety and Health (NIOSH) identified hearing loss as the most common job-related disease in the United States. Previous field studies by NIOSH have shown A-weighted sound levels at the operator's station on roof bolting machines used in coal mines exceed 100 dB when drilling. Laboratory vibration measurements conducted while drilling indicated that drill steel acceleration levels greatly exceed those of the drill motor, drill motor cover, the roof support plate, and the drilled media. Sound level measurements performed with parts of the drilling apparatus and the drilled media wrapped in lead-fiberglass barrier-absorber blankets revealed that the drill steel is the dominant noise source. To evaluate the ability of a partial-height barrier to reduce operator noise exposure, 80% of the drill steel length was encapsulated in a quilted lead-fiberglass barrier-absorber sleeve. The partial-height barrier reduced the time-weighted average sound level (TWA) by 9.8 dB for the Mine Safety and Health Administration (MSHA) Permissible Exposure Level (PEL) criteria and 9.3 dB for the NIOSH Recommended Exposure Limit (REL) criteria.

Primary subject classification: 14.3.2; Secondary subject classification: 41.3

1 INTRODUCTION

Noise-induced hearing loss (NIHL) continues to be one of the most common diseases in the mining industry affecting an overwhelming 90% of coal miners in the United States[1]. Noise exposure data collected by the Mine Safety and Health Administration (MSHA) from 2000 to 2005 documents the roof bolting (RB) machine is one of the top three mining machines responsible for noise overexposure in coal mining[2]. During this period of time, MSHA measured the noise exposures of more than 56,000 mining machine operators (see Table 1). RB machine operators were sampled more than 6,200 times. Of these samples, there were 1,086 records of RB machine operators acquiring a noise dose equal to or exceeding 100% based on the MSHA PEL criteria. In other words, approximately 17.5% of the sampled RB machine operators reached or exceeded the PEL on the day their noise exposure was measured. Only continuous mining machine operators (42%) and bulldozer operators (18.4%) had a higher frequency of exceeding the MSHA PEL.

The RB machine is an integral part of the room-and-pillar mining process. These machines are used to drill holes and then to install roof bolts which support the roof of the mine as shown in Fig. 1. To drill the hole, a drill steel, a hollow rod with either a hexagonal or circular cross-section, is inserted into the chuck of the RB machine and a drill bit is affixed to the top of the drill steel. The RB machine spins the drill steel and forces the bit into the rock. As the hole is drilled, a vacuum system sucks the cuttings down through the drill steel and into a dust collection box. The number of roof bolts installed by an operator during a work day depends on the roof control plan, the number of working faces, the number of working RB machines, and the production rate. Several mining companies indicated a RB machine operator might install between 70 and 90 roof bolts during a shift. An estimated 100 million roof bolts are installed in mines across the United States each year[3].

This paper presents the noise and vibration assessment of a RB machine conducted by the NIOSH Office of Mine Safety and Health Research (OMSHR) in Pittsburgh, PA. The objectives of this work were to identify dominant sources of drilling noise and to determine the merit of simple noise controls. Prior to designing noise controls that reduce the sound level at

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Table 1—Machine operators sampled and the exposure rate.

Machine	Number Sampled	PEL > =100	% over PEL
Bulldozer	6,473	1,190	18.4
Continuous Miner	5,082	2,134	42.0
Front End Loader	6,649	368	5.5
Roof Bolter	6,215	1,086	17.5
All Other Machines	21,638	2,380	11.0
Not Listed	10,337	1,145	11.0
Total	**56,434**	**8,303**	**14.7**

the operator's ear during drilling, the sources of drilling noise must be identified. The drilling apparatus consists of many components that may radiate noise during drilling. Moreover, the drilled media could also be a significant noise source.

To help determine if the drilling apparatus and the drilled media are significant noise sources, vibration measurements were performed while drilling into a granite block. The sound pressure at the operator's ear and the vibration on various RB drilling components were measured simultaneously. Vibration data were collected on the drill-head motor, the drill-head motor cover, and the drill guide. In addition, vibration data were measured on the drill steel and the drilled media.

Next, several RB machine drilling components were wrapped in quilted lead-fiberglass blankets to determine if any of the wrapped components were significant sources of drilling noise. While drilling, the sound pressure at the operator's ear was measured with and without the components wrapped. The results of these tests were used to assess the contribution of each component to drilling noise. The results from these tests clearly identify the drill steel as the dominant noise generating component.

Finally, we examined the potential of using a partial-height barrier-absorber (PHBA) sleeve around the drill steel to reduce the operator's noise exposure. A cylinder, or sleeve, of quilted lead-fiberglass barrier-absorber was used to surround the drill steel. Approximately 80% of the length of the drill steel was contained within the cylinder. This enables the RB operator to see the top part of the drill steel when drilling begins. Once the cylinder makes contact with the bottom of the hole, the sound level may be reduced enough to significantly reduce the operator's exposure to noise. However, at the beginning of the hole, the sound level might remain unchanged.

Fig. 1—Operator drilling into the roof of a coal mine using a roof bolter.

(a) *(b)*

Fig. 2—Pictures of (a) HDDR with test fixture in HAC, and (b) close up of drilling area.

The effect of a PHBA on the operator's noise dose can be estimated using the time-varying sound level with the following[4]:

$$D = 100\left(\frac{T}{T_C}\right)2^{[L_i - L_C]/Q} \tag{1}$$

where D is the percent dose, T is the exposure time, T_C is the criterion time, L_i is the constant sound level during the measurement time, L_C is the criterion sound level, and Q is the exchange rate in decibels. The dose per hole can be computed using MSHA's PEL parameters[4], i.e., 90-dB criterion level, 8-hour criterion time, 5-dB exchange rate, and also using NIOSH's REL parameters[5], i.e., 85-dB criterion level, 8-hour criterion time, 3-dB exchange rate. The TWA can be calculated by rearranging Eqn. (1) to yield:

$$TWA = L_C + QLOG_2\left[\left(\frac{D}{100}\right)\left(\frac{T_C}{T}\right)\right] \tag{2}$$

where D is the percent dose, T is the measurement duration, T_C is the criterion time, L_C is the criterion sound level, Q is the exchange rate in decibels, and TWA is the time-weighted average sound level for the measurement duration.

2 EXPERIMENTAL SETUP

Measurements were conducted in the hemi-anechoic chamber at the OMSHR laboratory in Pittsburgh using a Fletcher Model HDDR roof bolting machine as shown in Fig. 2(a). A custom-made test fixture that is used to support the drilled media was secured to the floor in front of the RB machine. The test fixture consists of square cross-section welded steel tubes. The media to be drilled was held in place using chains tensioned by ratcheting load binders. To reduce noise radiated from the test fixture, urethane sheets were used between the chains and the rock and between the fixture and the rock to reduce vibration transmission. In addition, some of the tubes were filled with sand to reduce fixture vibration.

Holes were drilled using 34.9-millimeter diameter drill bits attached to a 1.22-meter long drill steel with a hexagonal cross-section. A microphone was positioned near the operator's right ear by tying it to the railing around the operator platform as shown in Fig. 2(b). Since the operator platform is connected to the drilling apparatus, the distance between the microphone and the operator's location and the distance from the microphone to the drill steel are nearly constant as the drilling location changes. An optical tachometer was used to measure the rotational speed of the drill steel. Both the sound pressure and rotational speed were recorded with a sampling frequency of 50 kHz with 16-bit resolution. The recorded sound pressures were subsequently post-processed to calculate the overall A-weighed sound pressure level, the A-weighted one-third-octave-band sound levels, and the A-weighted narrowband sound levels. The one-third-octave-band data was calculated with digital filters meeting ANSI S1.11[6]. The narrowband levels were calculated using a block size of 8192 data points with a Hanning window and 67% overlap processing.

2.1 Baseline Sound Pressure Measurements

Prior to collecting data while drilling into the granite block, two sets of measurements were performed without drilling. The first set of data was collected with only the electrical and hydraulic systems operating and the second set of data was collected with the electrical, hydraulic, and vacuum systems operating. After collecting data without drilling, three sets of measurements were performed while drilling into the granite block with rotational speeds of 200, 300, and 400 revolutions per minute (RPM) and a thrust of 9.4 kN. For each set of measurements, three recordings of approximately 15.5 seconds were collected using the microphone input to trigger the recording with a 0.5 second pre-trigger.

2.2 Vibration and Sound Pressure Measurements

Uniaxial accelerometers were mounted to the drill-head motor, the drill-head motor cover, and the drill guide using cyanoacrylate gel adhesive, as shown in Fig. 3. One uniaxial accelerometer was affixed to the granite block using epoxy. A total of five accelerometers were mounted on the drill steel. Four uniaxial accelerometers with a measurement range of

(a) (b) (c)

Fig. 3—Accelerometer locations on (a) drill-head motor and drill-head motor cover (b) drill-guide and (c) drill steel.

±10,000 g were stud-mounted to the drill steel using the manufacturer's recommended torque with a thin layer of lithium grease between the accelerometer and the drill steel. In addition, a uniaxial teardrop-style accelerometer with a measurement range of ±5,000 g was mounted to the drill steel using cyanoacrylate gel adhesive. Prior to attaching instrumentation cables to the drill steel accelerometers, a thin layer of medium strength thread locker was carefully applied to the first few threads of the accelerometer electrical connectors to prevent them from becoming loose during testing. A slip ring was fitted to the base of the drill steel to make it possible to measure the drill steel accelerations. The sound pressure at the operator's ear was measured with the set up described above.

Several data sets were collected with a rotational speed of 200 RPM and thrust settings of 9.43 and 28.3 kN. The data from two of the accelerometers were not used because their signals showed signs of make-and-break contact. Each recording was examined to determine when the rotational speed stabilized and data segments with steady rotational speed were saved. The data segments were post-processed to calculate the one-third-octave-band acceleration levels and the A-weighted one-third-octave-band sound levels. The average drill steel one-third-octave-band and narrowband acceleration levels were calculated using the results from the remaining three drill steel accelerometers. Once again, the narrowband levels were calculated using a block size of 8192 data points with a Hanning window and 67% overlap processing.

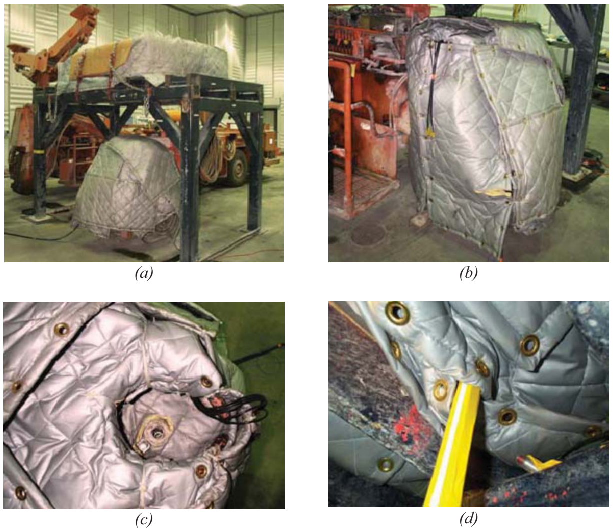


Fig. 4—Pictures of (a) full view of wrapped rock and drilling apparatus, (b) wrapped drilling apparatus, (c) wrapped drilling apparatus from above, and (d) interface of drill steel with wrapped rock.

2.3 Measurements with Wrapped Components

Baseline sound level measurements were conducted while drilling into a granite block. Data were collected at a rotational speed of 200 RPM with thrust settings of 9.43 and 28.3 kN. An optical tachometer was used to measure the rotational speed of the drill steel. Segments of data with a stable rotational speed were created for each recording. The segments were post-processed to calculate A-weighted one-third-octave band sound levels. The one-third-octave band spectra for a given configuration were averaged to reduce variability.

2.3.1 Wrapped drilling apparatus and granite block

First, the entire drilling apparatus and the granite block were covered with quilted lead-fiberglass barrier-absorber blankets as shown in Figs. 4(a) and 4(b). The drill steel, however, was left uncovered. When collecting data, the drill steel was inserted through the blanket wrapped around the granite block, as shown in Fig. 4(d). A tight fit was maintained between the drill steel and the granite block to prevent noise from the bit-rock interface from reaching the microphone. Next, the lead-fiberglass blankets were removed from the drilling apparatus and the measurements were repeated.

2.3.2 Wrapped drill steel

Since the drill steel accelerations were much higher than those of the rock and drilling apparatus, a series of

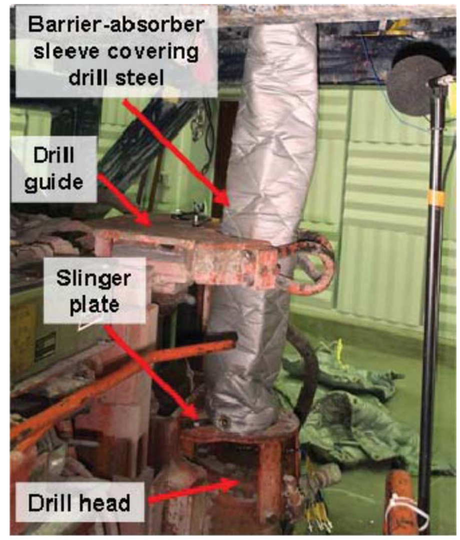


Fig. 5—Wrapped drill steel.

tests was performed to determine if the drill steel is the dominant noise source. The original granite block had no more drillable area, so a new granite block was positioned on the test fixture. A cylindrical sleeve of lead-fiberglass barrier-absorber was used to surround the drill steel (see Fig. 5). The top of the sleeve was sealed against the bottom of the granite block to keep noise radiated by the drill steel from escaping. The sound pressure at the operator's ear was measured with and without the cylindrical sleeve. These tests were conducted without any wrap around the drilling apparatus. Several measurements were made with a rotational speed of 200 RPM and thrust settings of 9.43 kN and 28.3 kN. The average overall A-weighted sound level and average A-weighted one-third-octave-band sound levels were calculated for each set of measurements.

2.4 Evaluation of a Partial-Height Drill Steel Barrier

To determine if a partial-height barrier could reduce the operator's noise exposure, a quilted lead-fiberglass PHBA sleeve was used to surround the top 1.2 meters of a 1.5-meter-long drill steel. A 1.2-meter-thick concrete block was used so full-depth holes could be drilled. A wire-wound potentiometer was connected to the drilling apparatus to measure drilling depth. First, six full-depth holes were drilled into the concrete block without the PHBA at 400 RPM with 18.8 kN of thrust. After drilling the first six holes, another hole was drilled with the PHBA. With the PHBA, the top 0.3 meters of the drill steel was exposed at the start of the hole.

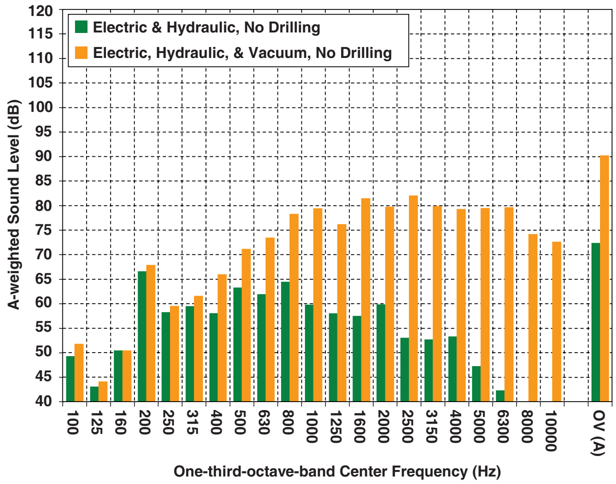


Fig. 6—A-weighted 1/3-octave-band sound levels without drilling for the electrical and hydraulic systems, and for the electrical, hydraulic, and vacuum systems

3 RESULTS AND DISCUSSION

3.1 Baseline Sound Pressure Measurements

The A-weighted one-third-octave-band and overall sound levels for the tests conducted with the electrical and hydraulic systems operating and with the electrical, hydraulic, and vacuum systems operating are shown in Fig. 6. The overall A-weighted sound level with only the electrical and hydraulic systems operating was 73 dB. With the vacuum system turned on, the overall A-weighted sound level increased to 90 dB. Clearly, the vacuum system is much more significant than the electrical and hydraulic systems. Figure 6 also shows that most of the sound energy with the vacuum system operating is in the 800 Hz through 6.3 kHz one-third-octave-bands.

Figure 7 shows a complete recording of the sound pressure at the operator's ear overlaid with the drill steel rotational speed for one of the drilling tests. As the figure shows, the rotational speed stabilizes approximately five seconds after drilling starts. Prior to post-processing the data, each recording was examined to determine when the rotational speed stabilized and a segment of data with a steady rotational speed was saved for each recording. The segments, which were approximately 10 seconds long, were then post-processed as previously described. This procedure was followed to reduce test-to-test variability resulting from the changing rotational speed at the beginning of the hole. For each set of data, average results were calculated using the post-processed data for each of the segments.

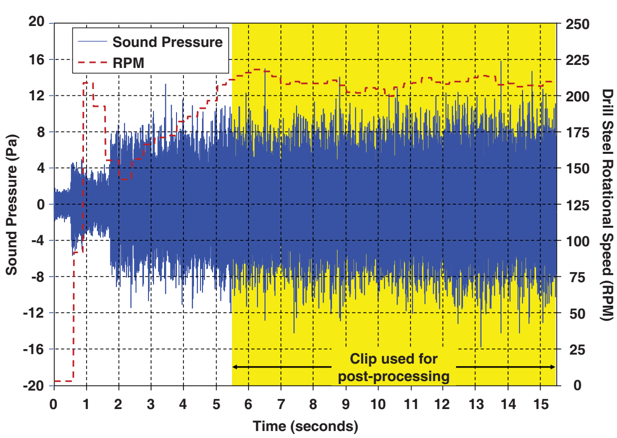


Fig. 7—Recorded sound pressure at operator's ear and drill steel rotational speed with clip used for post-processing highlighted

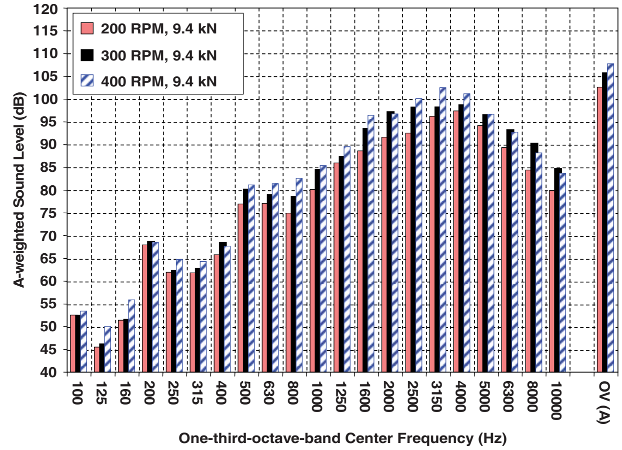
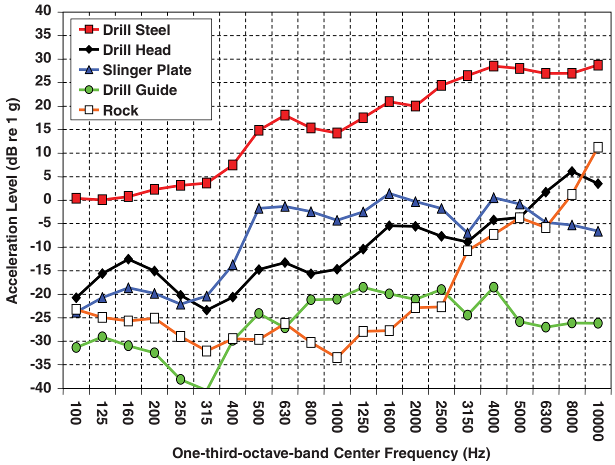


Fig. 8—A-weighted 1/3-octave-band sound levels for drilling in granite.

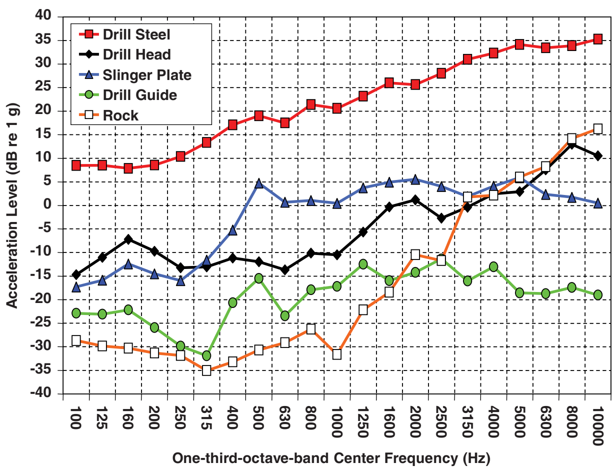
Figure 8 shows the resulting A-weighted one-third-octave-band and overall sound levels for drilling with 9.4 kN of thrust and rotational speeds of 200, 300, and 400 RPM. The overall A-weighted sound levels for 200, 300, and 400 RPM were 103 dB, 106 dB, and 108 dB, respectively. The 1.6 kHz through 6.3 kHz one-third-octave-bands accounted for more than 90% of the overall A-weighted sound level for each rotational speed. Since the overall A-weighted sound levels while drilling are more than 10 dB higher than the levels without drilling, the drilling process is clearly the dominant noise source when compared to the electrical, hydraulic, and vacuum systems.

3.2 Vibration and Sound Pressure Measurements

The one-third-octave-band acceleration levels of the drill steel, drill motor, drill motor cover, roof support plate, and granite block for drilling with 9.43 kN and 28.3 kN of thrust at 200 RPM are shown in Figs. 9(a) and 9(b), respectively. The drill steel acceleration levels are much higher than the levels at the other locations. In the 1.6 kHz through 6.3 kHz one-third-octave-bands, which

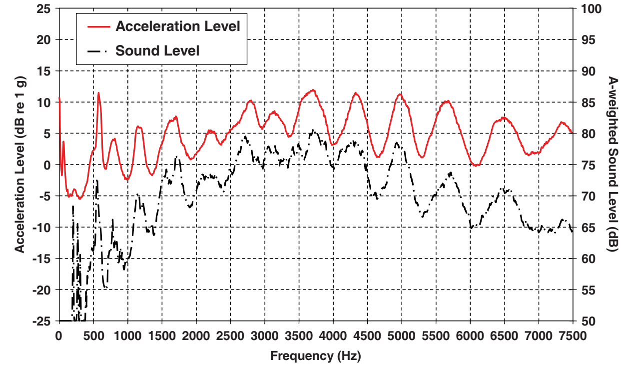


(a)

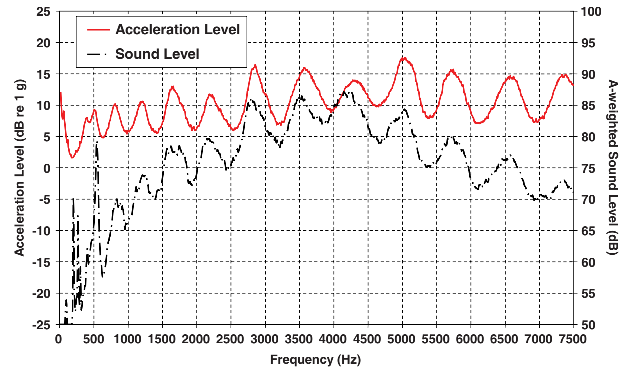


(b)

Fig. 9—Acceleration levels in 1/3-octave bands at 200 RPM for (a) 9.43 kN of thrust and (b) 28.3 kN of thrust.



(a)



(b)

Fig. 10—Narrowband drill steel acceleration levels at 200 RPM for (a) 9.43 kN of thrust and (b) 28.3 kN of thrust.

were shown to account for more than 90% of the sound level at the operator's ear, the drill steel acceleration levels are more than 20 dB higher than the acceleration levels for the other locations. Due to the relatively high vibration levels on the drill steel, it is possible that the drill steel is the dominant noise source while drilling, even though the surface area of the drill steel is relatively small. Figure 10 shows the narrowband drill steel acceleration levels and the A-weighted sound level at the operator's ear. The narrowband plots exhibit humps rather than sharp peaks. This characteristic is probably due to the slight variation in rotational speed and rock hardness as a hole is drilled. Above 1.5 kHz, the spectra are nearly identical in shape. This provides additional evidence that the drill steel could be the dominant source of drilling noise.

3.3 Sound Pressure Measurements with Wrapped Components

Since the vibration measurements revealed the drill steel had substantially higher vibration levels than the drill motor, drill motor cover, roof support plate, and drilled media, additional sound pressure measurements were performed using quilted lead-fiberglass barrier-absorber blankets to wrap potential noise sources. The objective of these tests was to determine if the drill steel is the dominant source of drilling noise. A granite block was used as the drilled media. Several measurements were made for each test configuration.

3.3.1 Wrapped drilling apparatus and granite block

Figure 11 shows the A-weighted one-third-octave band sound levels with no components wrapped; with the rock and drilling apparatus (chuck) wrapped; and with only the rock wrapped at 200 RPM for a thrust setting of 9.43 kN. Wrapping the drilling apparatus and rock would reduce the sound levels if either were a significant source of drilling noise. In the 2.5 kHz through 10 kHz one-third-octave-bands, which account for more than 80% of the sound level with no wrap, the in-band A-weighted sound levels varied by less than 2 dB for all three cases. Furthermore, the overall A-weighted sound level changed by less than 1 dB. Therefore, with respect to the overall A-weighted sound level, the rock and the drilling apparatus do not appear to be significant noise

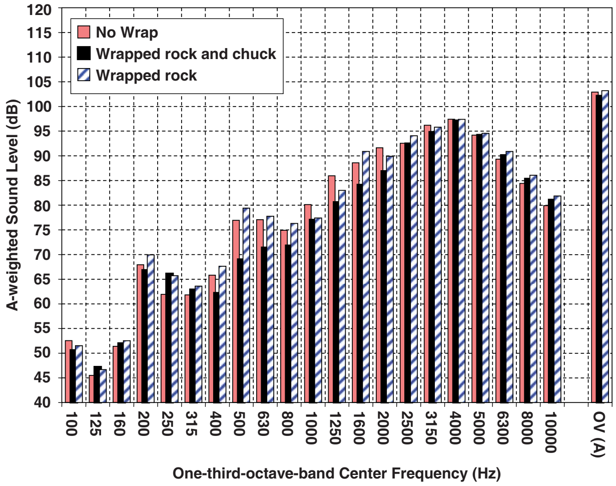


Fig. 11—A-weighted 1/3-octave-band sound levels with no wrap, wrapped rock and drilling apparatus, and wrapped rock for 200 RPM and 9.43 kN of thrust.

sources. In contrast, the sound levels in the 500 Hz through 2 kHz bands were reduced substantially by wrapping the drilling apparatus which indicates that the drilling apparatus may be a significant source of noise in this frequency range. However, in addition to blocking noise radiated by the drilling apparatus, the blanket also blocks the direct path of noise from the bottom of the drill steel to the microphone. So, the bottom of the drill steel may also be an important noise source.

Figure 12 shows the spectra for a rotational speed of 200 RPM with a thrust setting of 28.3 kN with the rock and drilling apparatus wrapped, and with only the rock wrapped. The sound levels in the 2.5 kHz through 10 kHz bands and the overall A-weighted sound level changed by 1 dB or less with the wrap removed from the drilling apparatus. This provides additional proof that the drilling apparatus is not a dominant source of drilling noise in terms of the overall A-weighted sound level. However, similar to the data shown in Fig. 11, the 500 Hz through 2 kHz bands show a significant increase in sound levels with the wrap removed from the drilling apparatus. Again, this indicates that either the drilling apparatus or the bottom portion of the drill steel is a significant noise source in this frequency range.

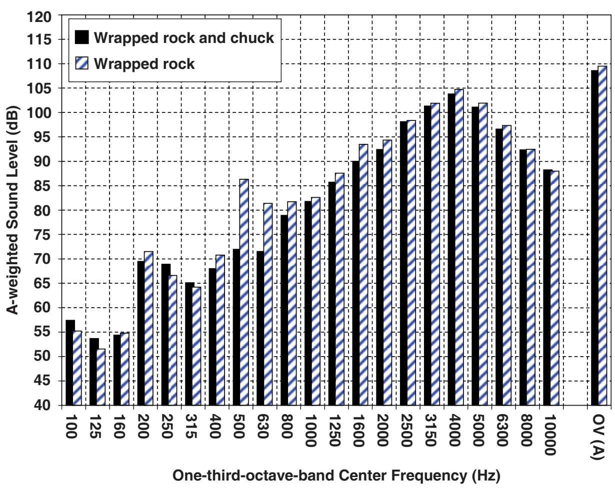


Fig. 12—A-weighted 1/3-octave-band sound levels for wrapped rock and drilling apparatus and wrapped rock for 200 RPM and 28.3 kN of thrust.

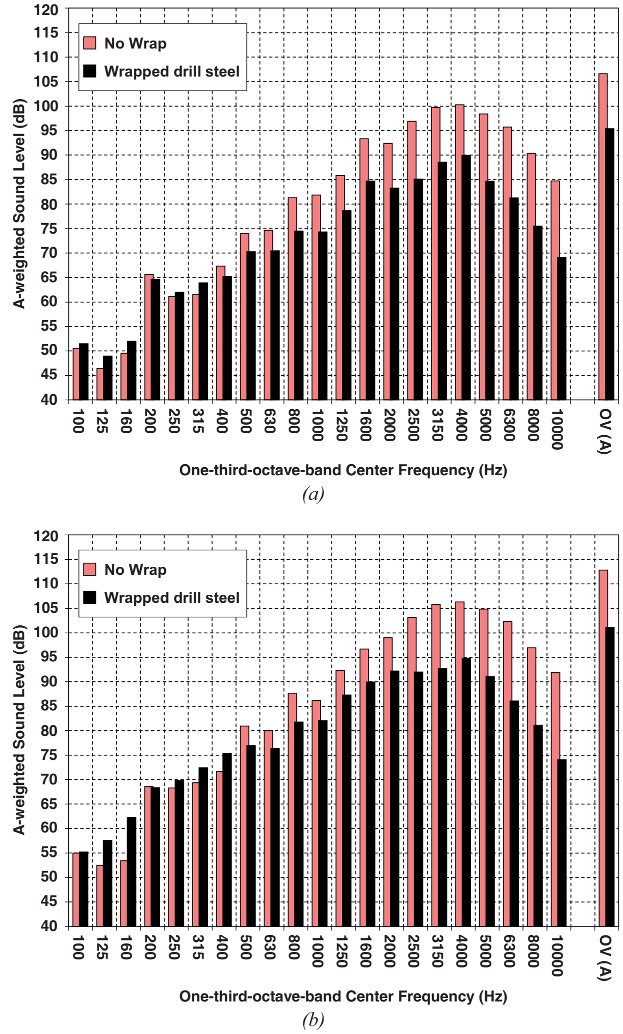


Fig. 13—A-weighted 1/3-octave-band sound levels without wrap and with wrapped drill steel at 200 RPM for (a) 9.43 kN of thrust and (b) 28.3 kN of thrust.

3.3.2 Wrapped drill steel

To determine if the drill steel is a dominant noise source, a quilted lead-fiberglass barrier-absorber sleeve was used to surround it. Figures 13(a) and 13(b) show the A-weighted one-third-octave-band sound levels with and without the barrier-absorber sleeve around the drill steel for thrust settings of 9.43 kN and 28.3 kN and a rotational speed of 200 RPM. Recall that a new granite block had to be used for these tests. For the tests without the sleeve around the drill steel, the overall A-weighted sound levels with the second granite block were approximately 3 dB to 4 dB higher than the levels measured using the first granite block. These differences could be due to changes in the location of the microphone relative to the test fixture and reflective surfaces on the roof bolter. Recall, the distance from the microphone to the operator was constant because the microphone was attached to the railing that moves with the operator platform. However, the distances from the microphone to the test fixture and reflective surfaces on the roof bolter change when the drilling apparatus is repositioned. Reflections from the test fixture and large surfaces on the roof bolter may have increased the sound levels. Another possibility is the second granite block was harder than the original granite block. Regardless of the cause, a new baseline sound level was established.

Surrounding the drill steel with the lead-fiberglass sleeve reduced the overall A-weighted sound level at the operator's ear by 11 dB for both thrust settings. In addition, the sound levels in the 1.6 kHz through 6.3 kHz one-third-octave-bands, which account for more than 90% of the overall A-weighted sound level, were reduced by 8.6 dB to 14.5 dB for the 9.43 kN thrust setting and 6.7 dB to 16.3 dB for the 28.3 kN thrust setting. These results indicate the drill steel is clearly the dominant source of drilling noise.

3.4 Evaluation of a Partial-Height Barrier

To determine if a partial-height barrier could reduce a RB operator's exposure to noise, sound level measurements were conducted with and without a partial-height barrier-absorber (PHBA) sleeve surrounding the drill steel. A PHBA sleeve was used to surround the bottom 0.9 meters of a 1.2-meter-long drill steel. The top 0.3 meters of the drill steel were left exposed to allow the operator to see the bit-rock interface. For the previously discussed measurements, granite was used as the drilled media due to its relatively consistent rock properties which yield reasonably repeatable results. Since each data set was collected for only 15 seconds, and the penetration rate with granite is low, the depth achieved was only about 15 cm, or around 10% of the drill steel length. But in field use, full-depth holes are drilled, so the entire drill steel would be inside the drilled hole.

As a hole is drilled, the surface area of the drill steel that is exposed decreases. So, the sound level could decrease as the hole depth increases. In addition, the drill steel can bend and contact the inner wall of the hole as the drill steel rotates. Rubbing between the drill steel and the rock may affect the radiated noise. In order to evaluate the potential of a partial-height drill steel enclosure to reduce drilling noise, the sound level at the operator's ear was measured while drilling full-depth holes with the PHBA sleeve around the drill steel. Since the available granite blocks were only about 60 cm thick, full-depth drilling could not be performed with granite. The only available material that would allow full-depth holes to be drilled was a 1.2-meter-thick concrete block.

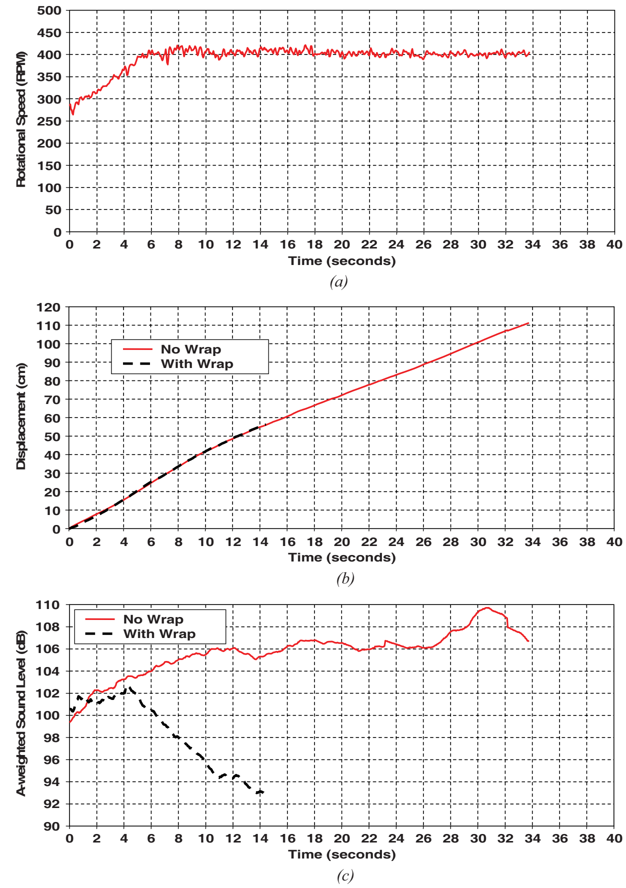


Fig. 14—Rotational speed, displacement, and A-weighted sound levels for drilling into concrete with 400 RPM and 18.8 kN of thrust. Results for full-depth drilling with no wrap around drill steel and partial-depth drilling with 80% of the drill steel wrapped.

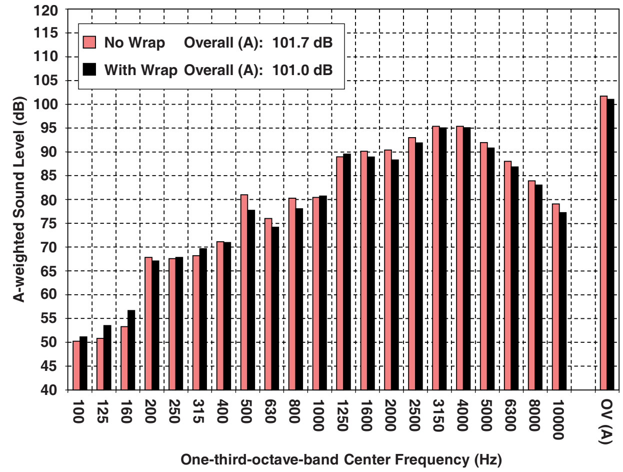
Figure 14(a) shows the rotational speed averaged for the six holes drilled without the barrier-absorber sleeve. The speed sensor could not be used when the sleeve was placed over the drill steel. As the figure shows, the rotational speed becomes relatively steady after approximately five seconds. The displacement averaged for the six holes drilled without and with the sleeve are shown in Fig. 14(b). As this figure shows, the slope of each line is nearly identical which indicates the penetration rates with or without the sleeve were approximately equal. Due to the presence of the sleeve, a full-depth hole could not be drilled. Drilling was stopped at a depth of about 55 cm when the sleeve was compressed into an accordion-like state.

The A-weighted sound level averaged for the six full-depth holes drilled without the sleeve and for the partial-depth hole drilled with the sleeve are shown Fig. 14(c). For the first five seconds, the sound levels without or with the sleeve are approximately equal. However, as the sleeve approaches the concrete block and the gap between the sleeve and the block is closed, the sound levels begin to decrease rapidly. Initially, the gap between the top of the sleeve and the concrete block was approximately 30 cm. Figure 14(b) shows that the drilling apparatus reached a displacement of 30 cm at about 7 seconds. Figure 14(c) shows that at 7 seconds, the A-weighted sound level with the sleeve was nearly 6 dB lower than the sound level without the sleeve. After the sleeve contacts the concrete block, the drilling apparatus forces the sleeve against the block, which improves the seal, and the sound level continues to decrease.

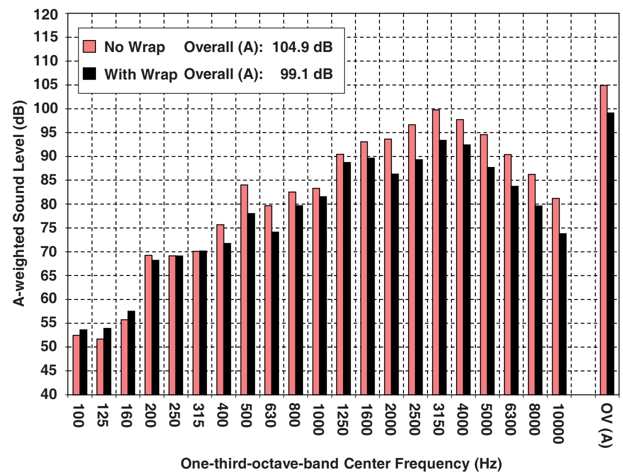
Figure 15 shows the time-averaged, A-weighted one-third-octave-band sound levels without and with the sleeve in 5-second increments. For the first 5 seconds (Fig. 15(a)), the spectra are nearly identical. The sound levels in the 2 kHz to 10 kHz one-third-octave-bands decrease by more than 5 dB between 5 and 10 seconds (Fig. 15(b)). From 10 to 14 seconds (Fig. 15(c)), after the sleeve is firmly pressed into the concrete block, the sound levels these bands decrease by more than 10 dB. The PHBA significantly reduces the sound level after it contacts the underside of the block.

The operator's noise dose per hole with and without the PHBA sleeve was estimated using Eqn. (1) with MSHA PEL parameters and also with NIOSH REL parameters. The A-weighted sound level was calculated from the raw time data in 0.05-second increments. For the holes without the PHBA sleeve, the average sound level was computed using all six sound level time histories. The average time to complete a full-depth hole without the sleeve was 33.75 seconds. For the purpose of evaluating the dose per hole and TWA with the PHBA, the A-weighted sound level was assumed to remain constant at 93 dB from 14 to 33.75 seconds (refer to Fig. 14(c)). For each 0.05-second increment, the noise dose was calculated according to Eqn. (1). The dose per hole was then calculated by summing the dose for each 0.05-second increment. The TWA for the 33.75-second-long sound level time histories were then calculated using Eqn. (2) for both MSHA PEL and NIOSH REL parameters.

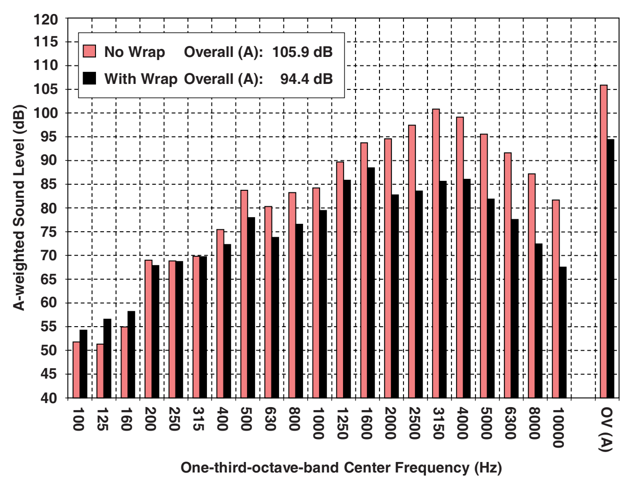
Table 2 shows the resulting dose and TWA according to MSHA PEL and NIOSH REL settings. Using the PHBA sleeve reduced the dose per hole from 1.08% to



(a)



(b)



(c)

Fig. 15—Comparison of time-average A-weighted 1/3-octave band sound levels from drilling full-depth holes into concrete without and with partial-height barrier-absorber wrap for (a) 0 to 5 seconds (b) 5 to 10 seconds and (c) 10 to 14 seconds.

Table 2—Dose per hole, number of holes allowed, time allowed, and TWA for MSHA PEL and NIOSH REL criteria without and with the partial-height barrier-absorber sleeve.

	MSHA PEL		NIOSH REL	
Parameter	No Sleeve	w/Sleeve	No Sleeve	w/Sleeve
% Dose per hole	1.08%	0.28%	15.50%	1.80%
Holes allowed	93	363	6.45	55.6
Time Allowed (hours)	0.872	3.4	0.0605	0.521
TWA (dB)	106	96.2	106.1	96.8

0.275% for the MSHA PEL criteria and from 15.5% to 1.80% for the NIOSH REL criteria. The TWA was reduced by 9.8 dB for the MSHA PEL criteria and 9.3 dB for the NIOSH REL criteria.

It is important to note that in real field conditions the reductions in dose and TWA might be higher because the material drilled in the field would probably be much harder than concrete. Harder materials tend to increase the noise due to drilling. Nonetheless, these results indicate that a partial-height barrier between the operator and drill steel has the potential to substantially reduce the operator's noise exposure.

A partial-height barrier could be connected to the drilling apparatus so the operator could change the drill bit and see the bit-roof interface when drilling begins. After some penetration has occurred, the operator may no longer need to see the drill steel. The biggest design challenge for this type of noise control would be how to limit its interference with the RB operator's ability to do his job.

4 CONCLUSIONS

A series of sound pressure and vibration measurements were conducted to help identify the significant noise generating components on a RB machine. First, it was determined that the A-weighted sound levels measured while drilling are approximately 10 dB higher than the levels due to electrical, hydraulic, and vacuum system noise. Vibration measurements revealed that the drill steel exhibits higher vibration levels than the drill motor, drill motor cover, top plate, and drilling media. Quilted lead-fiberglass barrier-absorber blankets were used to block the noise from the machine components involved in the drilling process. Wrapping the drilling apparatus and the drilling media reduced the overall A-weighted sound level at the operator's ear by less than 1 dB(A). Conversely, completely enclosing the drill steel in a quilted lead-fiberglass barrier-absorber sleeve reduced the sound level at the operator's ear by 11 dB. Placing a PHBA sleeve around 80% of the height of a 1.2-meter-long drill steel reduced the TWA per hole by more than 9 dB for both MSHA PEL and NIOSH REL criteria when drilling into concrete. The most important outcome from this work was the identification of the drill steel as the dominant source of drilling noise on RB machines. The data indicate a partial-height drill steel enclosure could be an effective noise control for RB machines.

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