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Estimated Sound Power Radiated by Surfaces on a Continuous Miner Tail Section Using Vibration Measurements

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ABSTRACT
Miners in underground coal mines experience prolonged exposure to high noise levels, often with A-weighted sound levels in excess of 90 dB. Field tests have shown that the continuous miner conveyor is a dominant noise source. This paper will identify the most significant noise-radiating surfaces on the continuous miner tail section using vibration levels and surface areas to estimate the sound power levels of each surface. In addition, using five test cases, this study will examine the effects of three engineering noise controls on the surface-averaged vibration levels and average sound levels measured with four microphones located two meters from the tail section. The noise-radiating surfaces of the conveyor's tail section include the top and bottom decks, the sideboards, and the flex plates. Emphasis is placed on the changes in the estimated sound power levels in the 500 – 2500 Hz 1/3-octave bands since this frequency range accounts for 80-85% of the sound energy near the tail section. The results show that the bottom deck is the most significant noise radiator for the untreated miner. Installing a coated bottom deck reduces the estimated sound power level radiated from the bottom deck by 11 dB and the average sound level by 2 dB. Using a coated tail roller results in reductions of the estimated sound power levels for individual components from 1 to 4 dB and reduces the average sound level by 2 dB. Coating the slide plate has little effect on both the estimated radiated sound power levels and the average sound level. The test results indicate that modifications that reduce flex plate vibration and reduce energy transfer from the tail roller into the tail section will be effective in reducing noise when combined with a coated tail roller and coated return deck.

1. INTRODUCTION
Noise-induced hearing loss is among the most critical health issues affecting miners today. NIOSH studies of 17,260 audiograms for 2871 coal miners show that 80% of coal miners have a moderate to profound high-frequency hearing loss by age 64.[1] In addition, at age 50, 90% of miners have a hearing impairment by the NIOSH definition (an average Hearing Threshold Level of 25 dB or greater for the 1000, 2000, 3000, and 4000 Hz frequencies) compared to only 10% of people without occupational noise exposure.

Mining equipment that is used to drill and cut rock, coal, or other materials radiates noise due to the impacts associated with the cutting and drilling processes. In addition, conveying mechanisms that move the cut media to the point where a haulage vehicle carries it away can generate high noise levels. Some conveyors utilize a chain with metal bars called flight bars to move the material to the loading point. Impacts between the chain and various components of the conveyor can cause excessive noise levels.

A continuous miner is a machine that uses a rotating cylinder, or cutting drum, with bits attached to its outer surface to cut coal. The coal is then loaded onto the gathering pan of the conveyor deck by rotating arms. A conveyor chain with flight bars moves the cut material along the top deck from the front of the machine to the rear of the miner where a haulage vehicle loads the material and carries it away. The conveyor chain is driven from the front of the miner via a sprocket. At the rear of the miner, the tail roller guides the conveyor chain back to the front of the machine via the return deck. The slide plate holds the tail roller in place between the side rails.

The conveyor is one of the dominant noise sources on a continuous miner. Since the operator position is located near the rear, or tail section, of the miner, reducing the noise radiated by the tail section is necessary to reduce operator noise exposure. The tail section noise affecting the operator is due to the flight bars scraping the top deck and impacting the tail roller and other locations on the machine along the return path exciting the structure which radiates noise.

Huggins and Remington studied the noise generating mechanisms of the conveyor tail section of a loader, which is similar to a continuous miner without a cutting drum.[2] A fixture was fabricated using the tail section of a loader. Noise and vibration measurements were conducted in a reverberation chamber to determine the most significant sources of noise. The dominant noise-generating mechanism was found to be the chain impacting the tail roller followed by the chain impacting and scraping on the top and the bottom conveyor deck. An isolated tail roller consisting of a steel sleeve over a rubber coated tail roller and isolation strips for the top and bottom plates were developed. Application of these treatments was found to reduce the overall A-weighted sound level by 11 dB for tests conducted on the test fixture. The researchers point out that, although there is a general similarity in the noise generating mechanisms of conveyors, the relative ranking of the noise-generating mechanisms may vary widely between machines.

Galaitsis, Madden, and Andersen evaluated the acoustic performance and durability of constrained layer damping treatments applied to the top and bottom decks and the side rails of continuous miners.[3] Six treated and eleven untreated continuous miners were tested underground. The results indicated that the average reduction in the A-weighted sound level at the operator's position was 5 dB with an empty conveyor and no cutting. With a loaded conveyor, the A-weighted sound level was reduced by 2 dB. After one year of operation, no significant reduction in the acoustic performance of the treatment was observed. The researchers also evaluated the performance of resilient wear strips mounted to the conveyor deck. Above ground tests showed the strips to be both durable and effective at reducing noise. However, underground testing showed excessive wear of the strips. The researchers suggested modifying the design of the strips to improve their durability.

2. EXPERIMENTAL PROCEDURES / ANALYSIS METHOD

Vibration measurements were used to estimate the A-weighted sound power radiated from the surfaces of the tail section of the continuous miner using acceleration measurements.[4] The vibration data were measured following *ISO/TR 7849:1987 Acoustics – Estimation of airborne noise emitted by machinery using vibration measurement*. The major noise-radiating surfaces of the tail section that were examined include the left and right side rails, the left and right flex plates, the top conveyor deck, and the bottom conveyor deck (see Figure 1).

Four microphones were used to measure the sound pressure during testing (see Figure 2). One microphone was located two meters above a reference box encompassing the tail section and centered across the top deck. Three additional microphones were positioned at a height of 1.5 m and located two meters from the left, to the rear, and to the right of the reference box. The microphones to the left and right of the tail section were centered on the length of the reference box.

Using beeswax, ten to twelve accelerometers were mounted on the left and right side rails, left and right flex plates, and the return deck. Figures 3 and 4 show the accelerometer locations used on the return deck and left flex plate, respectively. For the top deck, accelerometers were embedded in the underside of the deck by drilling 6-mm diameter holes approximately 6 mm deep. Epoxy was then used to mount accelerometers into the holes. Shallow grooves were made in the underside of the top deck to run the cables to the outside of the machine (see Figure 5).

A water spray of approximately 3.79 l/min (1 gal/min) was applied to the top deck to simulate the wet environment encountered in mining. The conveyor was operated and the resulting accelerations and sound pressures were measured at a sample rate of 25 kSamples/sec with 16-bit resolution. The digitized data were subsequently A-weighted. The accelerations were integrated to determine the vibration velocities. Third-octave filtering was then applied to the A-weighted sound pressures and vibration velocities. For each test, the surface-averaged mean square velocity on each surface and the four-microphone averaged sound levels were calculated. The surface-averaged vibration levels were used with the surface areas to estimate the sound power levels of radiation from each test surface.

Baseline tests were performed with no engineering noise controls applied to the miner. Following the baseline tests, the effects of several engineering noise controls on the sound power radiated by the test surfaces and the average sound levels were examined. The additional tests were performed with the following treatments:

1. Coated return deck;
2. Coated tail roller;
3. Coated return deck and coated tail roller;
4. Coated slide plate.

The sound power radiated by a vibrating surface may be determined by

$$P = \sigma \rho c S \overline{v^2} \tag{1}$$

where σ is the radiation ratio, ρc is the specific acoustic impedance of the fluid, S is the surface area, and $\overline{v^2}$ is the mean square surface-averaged velocity. For the purposes of comparing the radiated sound power from each surface, the radiation ratio of each surface was assumed to be 1. The estimated sound power level in decibels may then be found to by

$$L_w = 10\,log\left(\frac{S}{S_0}\right) + 10\,log\left(\frac{\overline{v^2}}{v_0^2}\right) \tag{2}$$

where S_0 is the reference surface area taken to be 1 m^2, and v_0 is the reference mean square velocity taken to be 50 x 10^{-9} m/s according to *ISO/TR 7849*.

3. RESULTS & DISCUSSION

Baseline tests were conducted with no treatments applied to the machine and the data were processed according to the previously discussed procedures. The four-microphone average sound level for the baseline conditions is shown in 1/3-octave bands in Figure 6. The average A-weighted sound level for the baseline tests was found to be 99 dB. The baseline data show that the 500 – 2500 Hz 1/3-octave bands account for 80 – 85 % of the overall A-weighted sound level. Therefore, the estimated A-weighted sound power levels in the 500 – 2500 Hz 1/3-octave bands from each surface were examined. Figure 7 shows a bar plot of the estimated A-weighted sound power level attributed to each test surface in the 500 – 2500 Hz 1/3-octave bands. These data were calculated using equation 2. The sound power levels due to each surface may not be correct in an absolute sense due to the assumption that the radiation ratio is unity. However, the data can be used to assess the relative contribution of each surface. As the figure shows, the return deck is the most significant noise radiator for the baseline conditions followed by the left side board, the left flex plate, the right side board, the right flex plate, and the top deck. These findings indicate that the first attempt at controlling noise must focus on reducing the vibration of the return deck.

As the flight bars on the conveyor chain begin their return, the flights have been observed to impact the beginning of the return deck. This observation correlates with the high vibration levels and estimated sound power for the return deck under baseline conditions. To address this problem, a urethane coating was applied to the return deck (see Figure 8) to decrease the energy transmitted to the return deck by the flight bar impacts. Figure 9 shows the estimated A-weighted sound power levels in the 500 Hz – 2500 Hz 1/3-octave bands for each test surface with the coated return deck compared to the baseline tests. The figure shows that the sound power level from the return deck dropped by 11 dB with the coated return deck. Reductions of 1 to 2 dB occurred on the other test surfaces. With the coated return deck, the figure shows that the most significant noise radiators are the left side board and left flex plate followed by the right side board and right flex plate. The return deck is shown to be the least significant noise radiator. The average overall A-weighted sound level dropped to 97 dB, a 2-dB reduction from the baseline sound level. The results show that the coated return deck is effective at both reducing the average sound level and the return deck radiated sound power. However, the significantly lower sound power level reductions on the other test surfaces indicate that other sources of excitation may be controlling the A-weighted sound level.

The flight bars also impact the steel tail roller transmitting energy into the tail section via the tail roller guides, slide plate, and tension springs along the tail section. A urethane-coated tail roller (see Figure 10) was developed to reduce the forces transmitted by these paths. Figure 11 shows the estimated radiated sound power level in the 500 – 2500 Hz 1/3-octave bands for each test surface with the coated tail roller compared to the levels for the baseline test case. The figure shows that the reductions in radiated sound power for individual surfaces ranged from 1 to 4 dB. The most significant reduction occurred for the left side board followed by the right side board, the top deck, and the return deck. The reductions in the sound power levels for the left and right flex plates were determined to be 1 dB. With the coated tail roller, the dominant noise-radiating surface is the return deck followed by the left side board, the left flex plate, the right flex plate, the right side board, and the top deck. The data show that coating the tail roller results in higher reductions of overall radiated sound power compared to the coated return deck. However, the coated return deck reduced the most dominant source better than the coated tail roller. The average overall A-weighted sound level was reduced from 99 dB for the baseline test case to 97 dB with the coated tail roller.

Since both the coated return deck and coated tail roller reduced the estimated radiated sound power levels and the average overall A-weighted sound level, tests were performed with both treatments in place (see Figure 12). Figure 13 shows a comparison of the estimated sound power levels in the 500 – 2500 Hz 1/3-octave bands with the coated return deck and coated tail roller compared to the levels for the baseline continuous miner. The sound power level attributable to the return deck, the most significant source for the baseline machine, was reduced by 16 dB. Reductions in sound power level for the left side board, top deck, and right side board were 7, 8, and 14 dB, respectively. The sound power level from the left and right flex plates remained relatively unchanged with reductions of 2 dB. The average overall A-weighted sound level dropped from 99 dB for the baseline test case to 95 dB with the coated return deck and coated tail roller. With these treatments, the data show that the left and right flex plates are the dominant noise-radiating surfaces followed by the left side board. The test data indicate that treatments that reduce the flex plate vibrations, such as constrained layer damping, will be effective in reducing the noise levels around the tail section when combined with the coated return deck and coated tail roller.

Since the slide plate is an element that transfers the tail roller-chain impact energy into the tail section, a coated slide plate (see Figure 14) was fabricated. The coated slide plate was installed and the coated return deck and coated tail roller were replaced with the non-coated components. Figure 15 shows the estimated sound power level for each test surface in the 500 – 2500 Hz 1/3-octave bands with the coated slide plate compared to the baseline test case. The figure shows that the return deck was the most significant noise-radiating surface followed by the left side board and left flex plate. Reductions in sound power levels were less than 1 dB for the left side board and 1dB for the return deck. The sound power level from the left flex plate increased by 2 dB. This increase is thought to be a result of the chain being moved towards the left side of the conveyor during installation of the coated slide plate. This would cause the flights to transmit more energy into the left flex plate. The small change in sound power levels from the other surfaces shows that the slide plate by itself is not effective at making a significant impact on the vibration levels. The average overall A-weighted sound level remained 99 dB.

Although the slide plate by itself is ineffective at reducing the surface vibrations, combining the coated slide plate with other treatments that reduce the force transmitted via the tail roller ends, slide plate, and springs would be effective. The test data with the coated tail roller prove that reducing the force applied at the tail roller would reduce the surface vibrations and sound levels. The next step would be to isolate the tail roller and slide plate from the tail section. To isolate these components effectively, all mechanical connections must be addressed. The existing design has steel-steel contact at the interface between the ends of the tail roller and the left and right side boards. In addition, steel compression springs are used on each side of the conveyor deck to apply tension to the chain. These paths must be addressed in addition to the contact between the slide plate and the tail section to further reduce energy transmission and radiated noise.

Figure 16 shows a comparison of the estimated radiated sound power for each surface in the 500 – 2500 Hz 1/3-octave bands in relation to each test case that showed significant reductions in the estimated radiated sound power. The average overall A-weighted 1/3-octave spectra for each test are plotted on Figure 17. Figure 17 shows that the coated slide plate had little effect on any of the 1/3-octave band sound levels. Individually, however, both the coated return deck and coated tail roller were effective at reducing the sound levels in the dominant frequency band. The data show that the coated tail roller is more effective than the coated return deck in reducing noise above 2500 Hz. Although the higher frequencies are currently insignificant, these reductions may play a more important role if other controls can reduce the noise levels in the 500 – 2500 Hz 1/3-octave band.

5. CONCLUSIONS

The return deck was the most significant noise-radiating surface for the baseline tests. Installation of a urethane-coated return deck decreased the estimated sound power level of radiation from the return deck by 11 dB in the 500 – 2500 Hz 1/3-octave bands and reduced the average overall sound level by 2 dB. The estimated sound power levels for the other test surfaces were reduced by 1 to 2 dB. Replacing the existing tail roller with a urethane-coated tail roller resulted in reductions in the estimated sound power level of radiation from individual surfaces from 1 to 4 dB and reduced the average overall sound level by 2 dB. Combining the coated tail roller and coated return deck reduced the estimated sound power level of radiation from the return deck by 16 dB compared to the baseline levels and reduced the average overall sound level by 4 dB. Using a coated slide plate was found to have minimal effects on the estimated radiated sound power levels and the average overall sound level.

REFERENCES

[1] John R. Franks, “Analysis of Audiograms for a Large Cohort of Noise-Exposed Miners,” Internal Report, National Institute for Occupational Safety and Health, Cincinnati, OH, pp. 1-7.

[2] Geoffrey G. Huggins and Paul J. Remington, “Noise Reduction of Conveyors Used in Underground Coal Mining Machinery,” Contract H0357085, Bolt, Beranek, and Newman, (Bureau of Mines OFR 109-77, 1976).

[3] A. Galaitsis, R. Madden, and D. Andersen, “Noise Reduction of Chain Conveyors Volume II,” Contract H0155113, Bolt, Beranek, and Newman, (Bureau of Mines OFR 171-83, 1983).

[4] *Acoustics – Estimation of Airborne Noise Emitted by Machinery Using Vibration Measurement,* Technical Report ISO 7849: 1987 (International Organization for Standardization, Geneva, Switzerland, 1987).

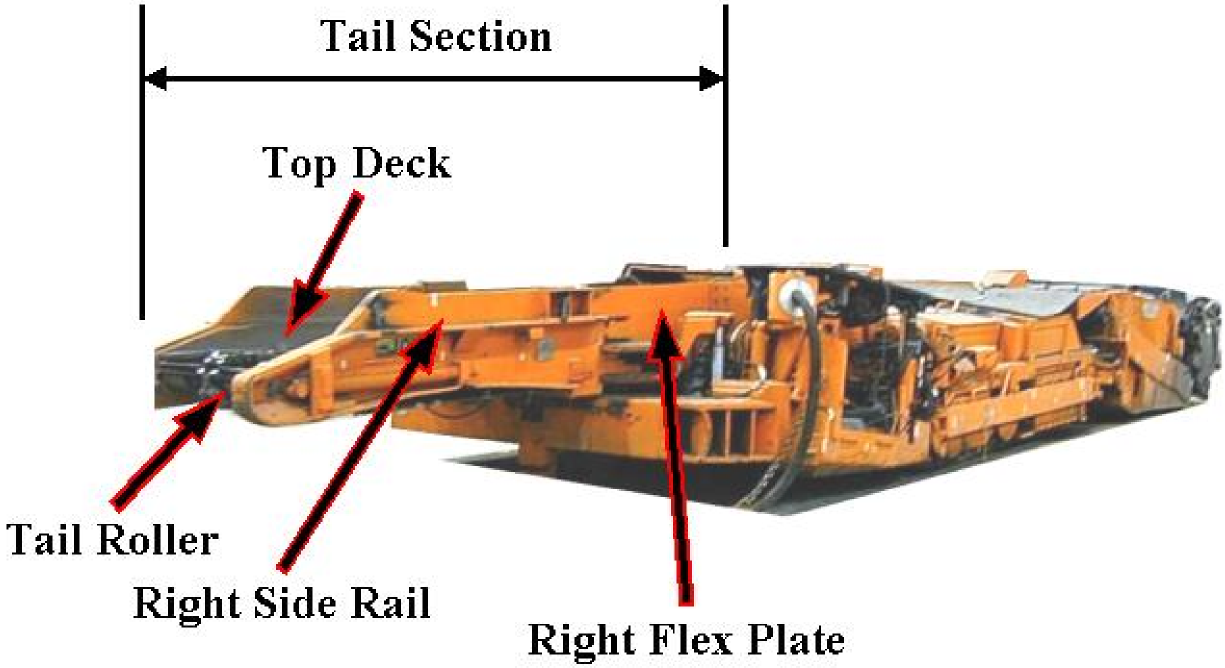

Figure 1. The continuous miner tail section.

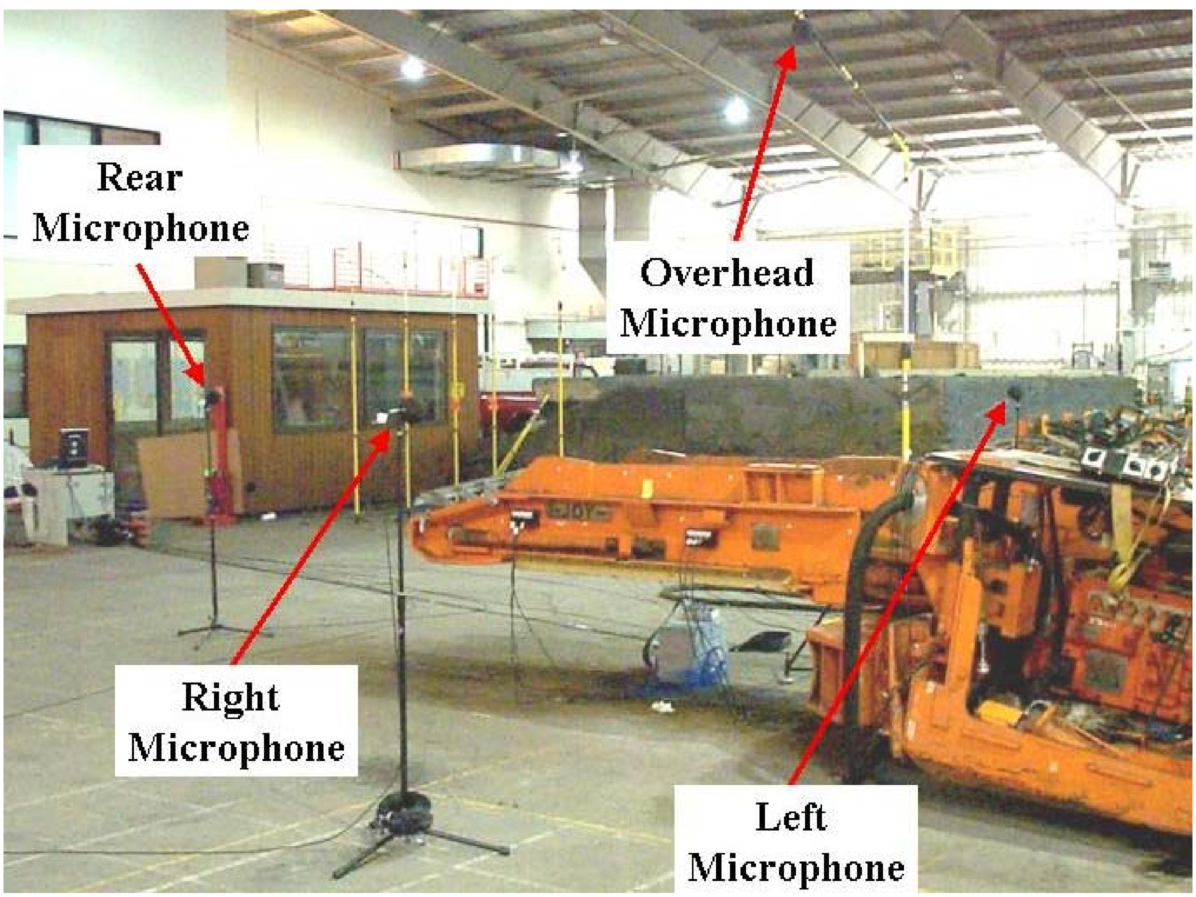

Figure 2. Microphone locations two meters from the reference box around the tail section of the continuous miner.

Figure 3. Accelerometer locations on the return deck of the continuous miner.

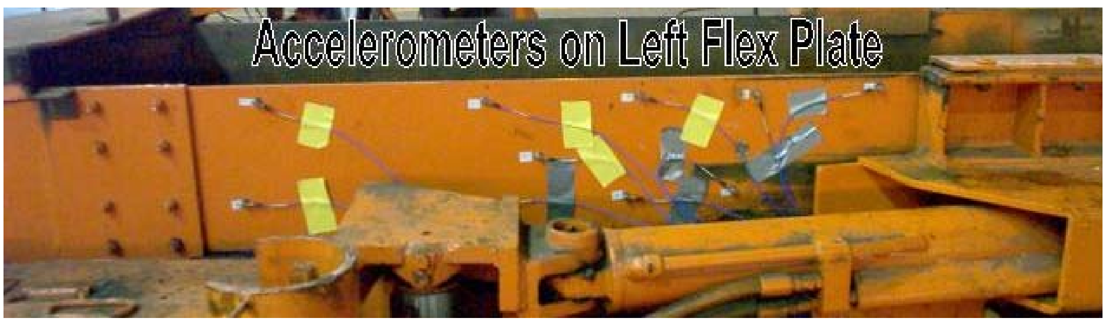

Figure 4. Accelerometer locations on the left flex plate of the continuous miner.

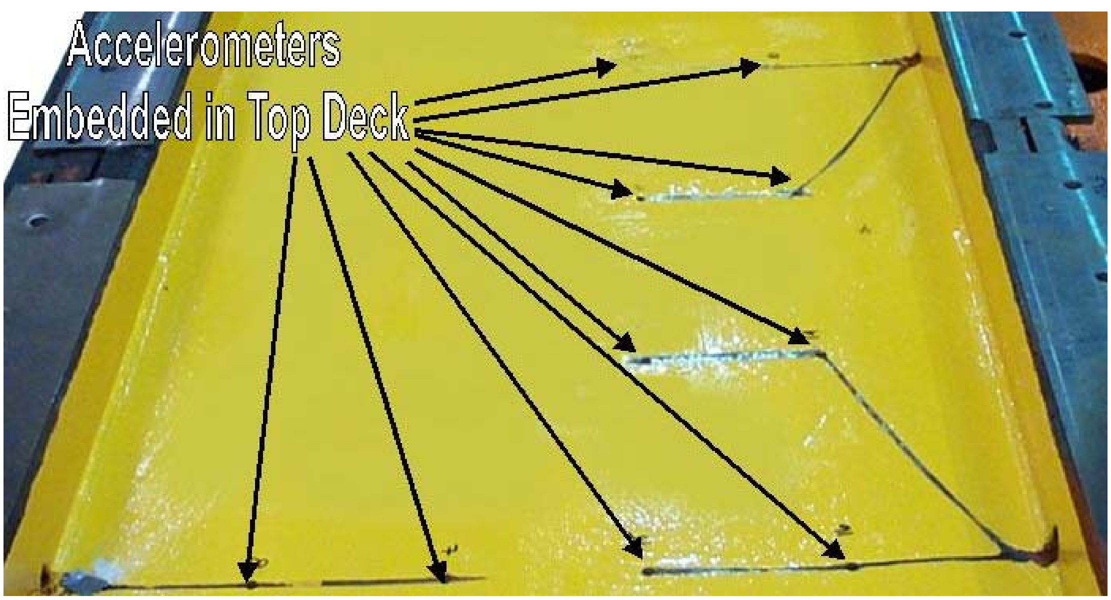

Figure 5. Accelerometers embedded in the underside of the continuous miner top deck.

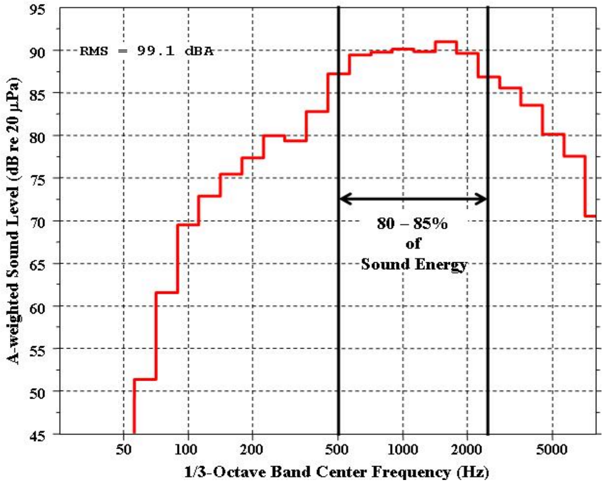

Figure 6. Average A-wtd 1/3-octave sound levels for the baseline continuous miner.

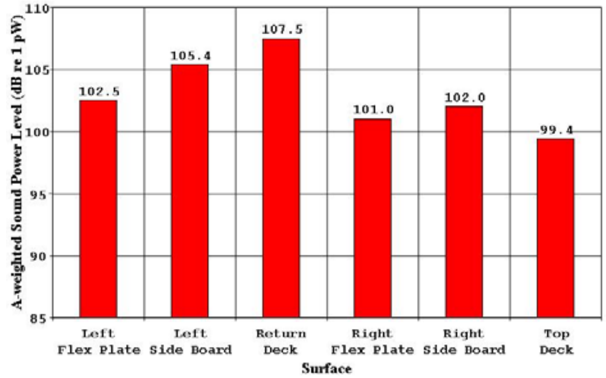

Figure 7. Estimated A-wtd sound power levels for each test surface in the 500 – 2500 Hz 1/3-octave bands for the baseline continuous miner.

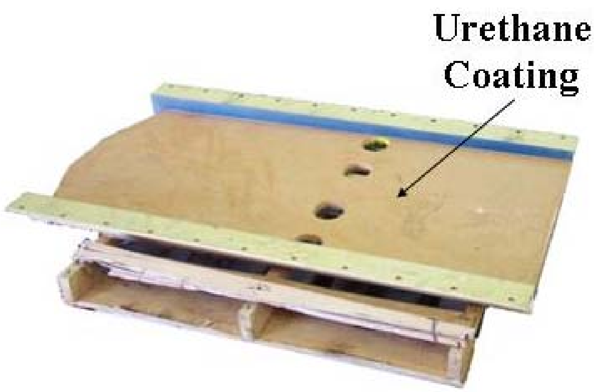

Figure 8. Coated return deck for the CM.

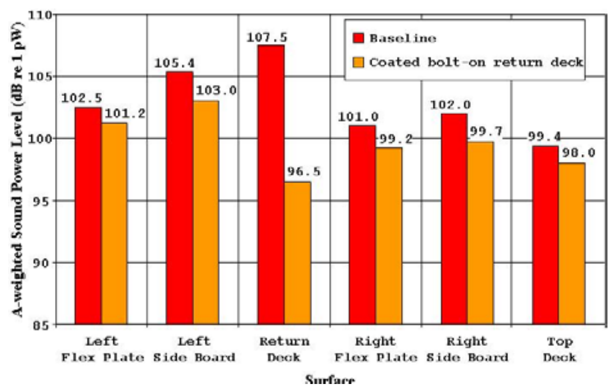

Figure 9. Estimated A-wtd sound power levels for each test surface in the 500 – 2500 Hz 1/3-octave bands for baseline versus coated return deck.

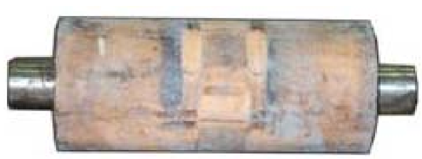

Figure 10. Coated tail roller for the CM.

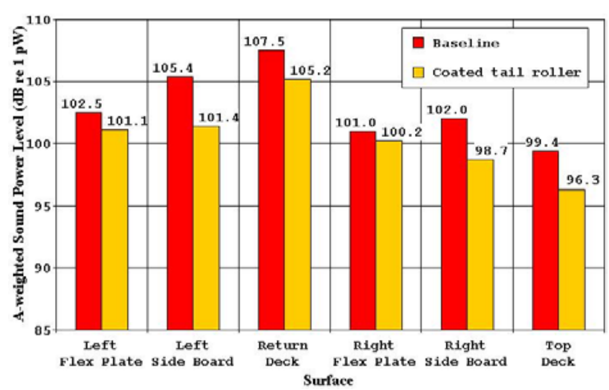

Figure 11. Estimated A-wtd sound power levels for each test surface in the 500 – 2500 Hz 1/3-octave bands for baseline versus coated tail roller.

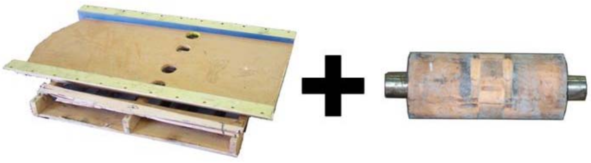

Figure 12. Coated return deck with coated tail roller.

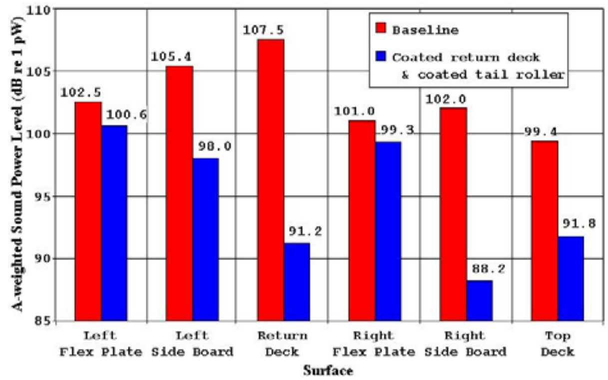

Figure 13. Estimated A-wtd sound power levels for each test surface in the 500 – 2500 Hz 1/3-octave bands for baseline versus coated return deck plus coated tail roller.

Figure 14. Coated slide plate for the continuous miner.

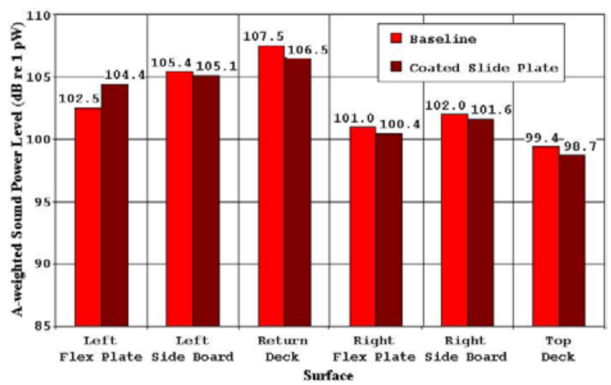

Figure 15. Estimated A-wtd sound power levels for each test surface in the 500 – 2500 Hz 1/3-octave bands for baseline versus coated slide plate.

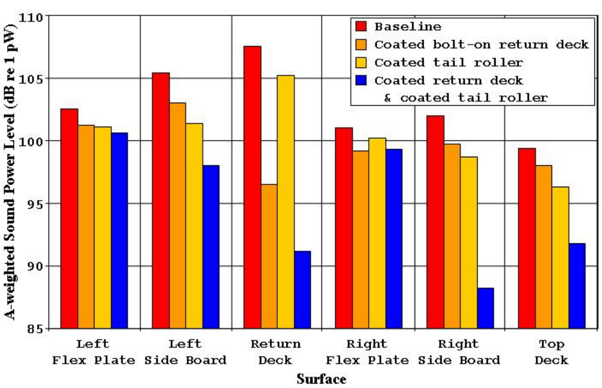

Figure 16. Estimated A-wtd sound power levels for each test surface in the 500 – 2500 Hz 1/3-octave bands for baseline versus effective noise controls.

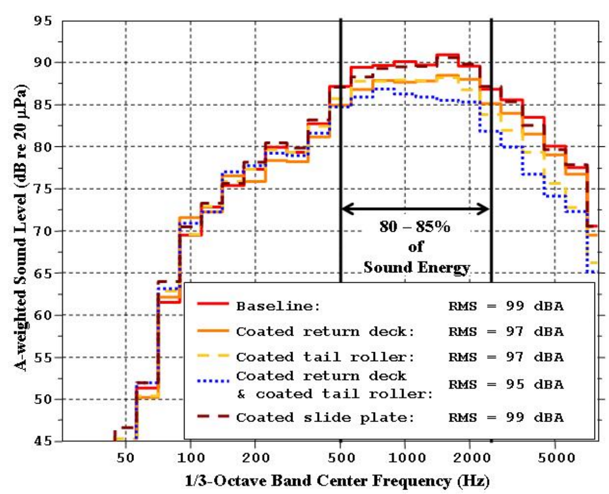

Figure 17. Average A-wtd 1/3-octave sound levels for the baseline continuous miner and continuous miner with attempted noise controls.