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Evaluation of Engineering Noise Controls for a Continuous Miner Conveyer System

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1. BACKGROUND

Many research projects on engineering controls for noise reduction in mining were conducted by the former U.S. Bureau of Mines, mostly under contracts from 1972 through 1986.[1] Contracts were awarded to determine which mining equipment was responsible for worker noise exposure over the permitted Federal Regulation level of 90 dBA for 8 hours. Dominate noise sources, for each piece of equipment was also determined. The final goal was to develop engineering noise controls for those pieces of equipment and then evaluate them. This was the general approach taken in each research project or contract. This paper deals with what is known about the control of noise from continuous miners, one of the most commonly used underground mining machines.

A literature review on continuous miners revealed that the relevant noise sources were divided into four categories: conveyor, cutting head, drive train, and motor noise. The dominate noise sources reported were the conveyor noise and the cutting noise.[2] Conveyor noise consists of impacts and scraping at various locations on the conveyor structure. These impacts are associated with discontinuities on the top and bottom decks, impacts between the chain and the tail roller, impacts on the sidewalls at path points of discontinuity under horizontal pivot, and impacts on the flex plate.[3] Scraping occurs along the entire length of the chain conveyor. The other dominate source, the cutting of coal, has also been addressed in past research.[4, 5, 6] The research presented in this paper only addresses the controls associated with the conveyor.

The literature suggests several effective treatments for noise control: retrofitting the chain conveyor with a urethane coating or a urethane sleeve on the chain flights, using a urethane coating or urethane sleeve on the tail roller, constrained layer damping of the decks, and the use of a modified take up plate.[7, 8] However, the in-mine durability of these concepts has yet to be proven for the conveyor system. This paper analyzes extensive noise and urethane durability testing on a Joy 14CM9 continuous miner's conveyor assembly, tail roller, and bottom plate conducted at the Pittsburgh Research Lab facilities. It will also discuss the initial underground testing results for the urethane-coated conveyor flights and tail roller.

2. INTRODUCTION

Underground continuous mining machines are subject to many variables that can affect the noise levels. Some of these variables cannot be controlled while others can. The acoustic environment in which the mining machine operates is a critical factor affecting the sound pressure levels measured at an operator's location. Underground mines are enclosed areas, which usually represents diffuse sound fields. The geometry and the composition of the coal or rock surfaces influence the overall sound level by affecting the number of rays reflected or absorbed. Mines also have various shapes, which can range from large rooms and pillars to rather small tunnels of various dimensions. All of these factors affect the overall sound energy as it is reflected or absorbed. Thus certain variables, which include geometry and composition of the surfaces, mine shape, and density of the medium, cannot be controlled in a mine environment.

However, the continuous miner can be redesigned or modified to reduce the sound being radiated from it. The first step is to locate the dominant sound sources and then develop engineering noise controls to reduce the noise being radiated from these sources and these noise controls must be able to withstand the harsh underground mine environment. The technique used in this research allows for the determination of the source of A-weighted radiated sound levels; the radiation patterns in octave and 1/3 octave bands; the computation of the A-weighted sound power level; and the conducting an underground wear evaluation of the various noise controls installed on the continuous miner.

Suffice to say that because coal mining is such a harsh environment, traditional approaches to noise control engineering solutions are not obvious, and are difficult or impossible to study effectively while a continuous miner is doing its work. Coal mining equipment must survive months of nearly continuous use, operating in environments where repair may not be possible. Therefore, coal mining equipment tends to be constructed of massive steel components that emit sound rather than dampen it.

The approach used in this study, therefore, uses the above ground facilities at PRL to determine the sound power level of each of the dominant noise producing mechanisms, to map the sound pressure levels existing around the entire machine, and document the relative contribution of candidate noise control solutions when compared to untested machinery. While a candidate approach may appear promising in above ground testing, the ultimate answer to its success lies in verification testing in the underground environment. At present, underground testing yields average noise exposure of operators using the modified equipment, some very limited measures of sound levels near the operating continuous miner, and most importantly visual observations of wear and tear on the treated machine components.

3. TECHNICAL APPROACH

Sound levels experienced by mining machine operators are determined both by the sound power radiated by the machine and by the acoustic characteristics of the mine environment. The sound power is the quantity of most interest, because this information can be used to estimate the sound pressure levels around the machine. Once the sound power of the machine is determined then a prediction can be made for the sound level that the operator would experience based on the acoustic characteristics of the environment. Also, knowing sound power allows for a direct comparison of noise for any machine tested under the same conditions.

Because of all the variations both geometrically and acoustically in underground mines it is difficult to achieve uniform test conditions. Since it is not possible to fully control the acoustic environment underground, testing a mining machine underground is of limited value. Testing the sound power emitted by machines and machine components is more easily controlled in a known test environment such as PRL's reverberation chamber and free field testing area. These facilities provide the ability to obtain accurate sound pressure levels and to calculate sound power levels in a controlled acoustic environment independent of the variables associated with underground mines. Never the less, in evaluating the wear or durability of the noise control the best approach is to evaluate it under normal operating conditions. In this study the procedure used for determining durability of the control consisted of examining the treated machine components for wear, cuts and tears, missing material, and weight loss.

4. PITTSBURGH RESEARCH LABORATORY TESTING FACILITIES

A. Reverberation Room

Reverberation rooms are used for determining sound power levels for machines, equipment, and sound components. They can also be used for measuring sound absorption coefficients of acoustical materials, transmission loss, and impact isolation of panels. Reverberation rooms are designed to have acoustically reflecting surfaces creating a perfectly diffuse sound field. A perfectly diffuse sound field cannot be obtained for all frequencies, but by properly designing a reverberation room satisfactory diffuseness can be achieved. The PRL reverberation chamber (Illustration 1) was designed for sound power testing of large mining equipment in conformance with ISO 3741.[9] It currently meets ISO 3741 in a usable frequency range of 100 Hz to 6300 Hz. The room is 18.31 meters long by 10.38 meters wide by 6.72 meters high, with an interior volume of 1277 cubic meters and a surface area of 766 square meters.

Because of the size of the mining equipment to be tested, a large volume room had to be built to comply with the ISO 3741 and ISO 3743 standards. ISO 3741 states that the volume of the sound source under testing preferably be less than 2% of the test room volume for precision method grade 1, or preferably less than 2.5% of the test room volume for engineering method grade 2. The walls are constructed of filled concrete blocks with the surface coated with non absorptive paint. Three humidifiers, a water line, and floor drains were installed to help keep the humidity at a set percentage and to keep the working environment clean. Table 1 provides the allowable limits for variations of temperature and relative humidity during testing in the reverberation room. Once the sound power of the mining machine is determined, the sound level that the operator would hear based on the acoustic characteristics of the environment can be predicted. Chart 1 shows a comparison of the sound power generated by the 14CM9 with and without the coated tail roller. Three tests were done on each configuration with an average sound power difference of 3.6 dBA (Chart 2).

B. Testing Procedures in a Free-Field Facility

In order to determine the noise field created by the continuous miner, a 24 by 16 meter grid of measurement positions was used to provide a free-field environment (Illustration 2). The coordinate system starts with a (0,0) point, located in the middle of the machine. Microphones were positioned at two-meter increments about the center. Originally, one meter increments were used, but only a .2 to .3 dB difference in accuracy was found between the one- and two-meter increment measurements. According to the ISO 3744 standard[5] this is within the allowable difference of .5dB. Each two-meter increment was represented by a mark on the ground establishing the grid. The sound level readings were taken at each of these locations and recorded on a data sheet. Tripods were used to hold the microphones and this allowed the microphone height to be adjusted. The microphones were positioned at ear level (which corresponds to a height of 1.53 meters).

When the measurements were completed the results were entered into a spreadsheet and then imported into the software program MATLAB for further analysis. Noise profiles were generated for each octave band, including overall A-weighted sound levels. The sound profiles of the continuous miner demonstrated sound levels and radiation patterns in predetermined frequency bands such as octave and 1/3 octave bands for each sound source of the machine.[10] This allowed for the determination and comparison of the different sound sources and noise controls.

5. NOISE TESTING RESULTS

The major noise sources on a Joy 14CM9 continuous miner, used for testing, were identified by testing each identified noise source independently. The conveyor was found to be a dominant source of noise. The noise level due to the conveyor was affected by the tension in the chain, with higher tensions resulting in higher noise levels. It was also determined that running the conveyor in wet conditions reduced the sound level significantly. A urethane coating was used to treat the conveyor flight bars in order to reduce the impact noise as the bars passed around the conveyor deck.

Based on the major improvements that have been made since the 1980s in urethane coatings, urethane was chosen to coat the dominant noise sources on the conveyor. Due to its elastomeric nature and combined properties, urethane was the prime candidate for this application. In researching the urethane coating, several issues had to be addressed, which included impact resistance, abrasion resistance, and MSHA approval for underground usage. The MHSA approval deals primarily with a low flame index of urethane coating. Also, for this coating to be a viable solution for noise reduction, it also needed to hold up in the harsh mining environment (e.g., a conveyor moving coal at over 450 ft/min). This coating cushions the blow of the bar on parts of the miner and reduces the resonant response of the flight bar. An impact test showed that large reductions in force on the flight bar was achieved above 500 Hz[10].

Through testing for durability and wear resistance, an 84 shore A durometer polyester MDI (Diphenyl Methane-4.4 Diisocyanate) and a 93 shore A durometer were chosen for this application. C.U.E., Incorporated's compound (PO#650 and PO#652) possesses the natural resiliency in the proper thickness to absorb noise-generating impact. The selected polyurethane coatings with properties are listed in table 2.

Two types of urethane coated flight bars, one type of urethane coated tail roller, and a urethane coated return deck were evaluated for noise controls. The free-field measurements showed the urethane coated flight bars tested 6 to 7 dBA sound pressure differences, the urethane coated tail roller tested 3.1 dBA sound pressure differences, and the coated conveyor bottom plate tested less than one dBA sound pressure difference. Illustrations 3 and 4 are profiles of free-field measurements before any engineering controls and after installing the coated flights, tail roller, and bottom plate respectively. The nine to ten dBA sound pressure differences was determined to be just cause to proceed with the underground testing phase of this project.[10]

6. WEAR EVALUATION UNDERGROUND

Two sets of ten flights were coated with the urethane material. One set was coated with the PO#650 urethane and the other set was coated with the PO#652 urethane. These were installed on a 12CM15 continuous mining machine with a thirty-inch conveyor in a Western Pennsylvania operational coal mine. This coal mine excavates bituminous coal consisting of about 60% shale. After 62 days of testing and 50,000 tons of coal and shale mined, the PO#650 urethane-coated flights had lost about 10% of their coating (Illustration 5). Three of the flight ends had lost their coating due to impacts with rocks. The PO#652 coated flights had lost about 50% of their coating and 7 flight ends were lost (Illustration 6). The urethane coated tail roller was installed on a different 12CM15 miner in the same Western Pennsylvania coal mine (Illustration 7). It showed little or no wear after 21 eight-hour shifts of use (Illustration 8). Sound pressure level measurements taken before and after the installation of the coated tail roller indicated a sound level difference of 2.8 dBA measured at the tail roller. Both underground tests are being continued until the coated conveyor chain flights and the coated tail roller fail. The expected life of an uncoated conveyor chain is approximately five to seven months.

The urethane-coated conveyor bottom plate tested displayed less than a one dBA sound power difference in PRL's Reverberation Chamber. There are no underground testing plans for the coated bottom plate, although it is being considered as part of the total noise reduction package.

The final phase of this research will be to test a complete chain with all the flights coated underground for both durability and noise reduction.

7. CONCLUSION

From the current test results, the PO#650 urethane coating is the best solution for noise reduction in the continuous miner conveyor system in respect to the PO#652 urethane coating, although the durability and wear testing are ongoing. Redesign of the conveyor chain flights to increase the amount of coating present and to reduce the clipping of the coating at the ends of the flight would further increase the life of the conveyor chain which could exceed the current 5 to 7 months. This greater life expectancy would make the anticipated 20% increase in the cost of the urethane-coated chain vs. an uncoated chain a more cost-effective solution for industry over time. The urethane-coated tail roller is holding up as expected and will probably not need to be modified. Another main advantage to this approach is that both the coated tail roller and coated conveyor chain can be installed underground, minimizing installation costs. This leads to the most important advantage, which is the reduced overexposure to noise that the miner experiences in his workplace. The next step is to put a fully coated chain on a miner underground and life test the chain for wear and noise at scheduled intervals. Finally, remove the coated chain at the end of its economic life and retest it in the reverberation room to verify the sound power.

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Allowable Limits in the Variation of Temperature and Relative Humidity

<table>
<tr><td rowspan="3">Ranges of temperature
θ
°C</td><td colspan="3">Ranges of relative humidity
%</td></tr>
<tr><td><30%</td><td>30% to 50%</td><td>>50%</td></tr>
<tr><td colspan="3">Allowable limits for temperature and relative humidity</td></tr>
<tr><td>-5 # θ < 10</td><td rowspan="2">± 1°C
± 3%</td><td>± 1°C
± 5%</td><td rowspan="2">± 3°C
± 10%</td></tr>
<tr><td>10 # θ < 20</td><td>± 3°C
± 5%</td></tr>
<tr><td>20 # θ < 50</td><td>± 2°C
± 3%</td><td>± 5°C
± 5%</td><td>± 5°C
± 10%</td></tr>
</table>

Table 1

URETHANE-COATING CHARACTERISTICS

	PO#650 – 84 DUROMETER	PO#652 - 93 DUROMETER
	Ultimate Tensile Strength:	
(ASTM D412-61T)	6000 PSI	5000PSI
	Tear Strength (lbs./in)	
Trousers Die		
(ASTM D1938)	250	400
Die C		
(ASTM D624)	470	650
Split Tear		
(ASTM D470)	140	200
	Tensile Modulus	
(ASTM D412-61 T)		
@ 50% Elongation	500 PSI	1100 PSI
@ 100% Elongation	700 PSI	1600 PSI
@ 200% Elongation	985 PSI	1900 PSI
@ 300% Elongation	1600 PSI	2300 PSI
	Elongation at Break	
(ASTM D-412-61 T)	550%	550%

TABLE 2

SOUND POWER COMPARISION FOR COATED TAIL ROLLER FROM PRL'S REVERBERATION CHAMBER

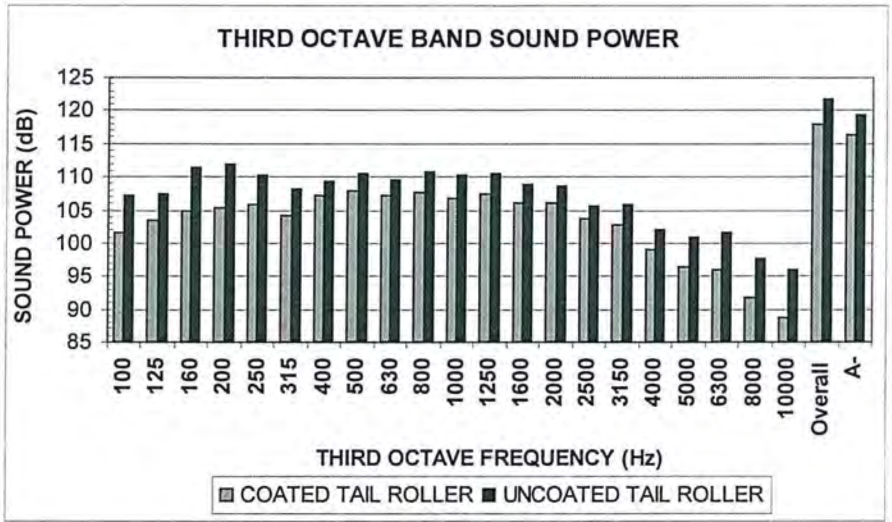

Chart 1

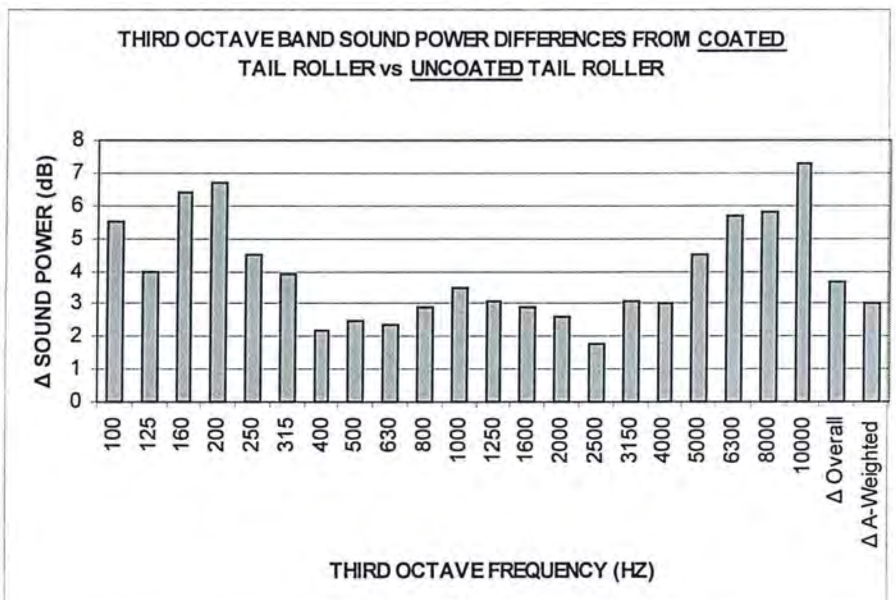

Chart 2

PRL REVERBERATION CHAMBER

Illustration 1

PRL FREE FIELD

Illustration 2

BASELINE SOUND PRESSURE MEASUREMENTS FOR JOY 14CM9 MINER

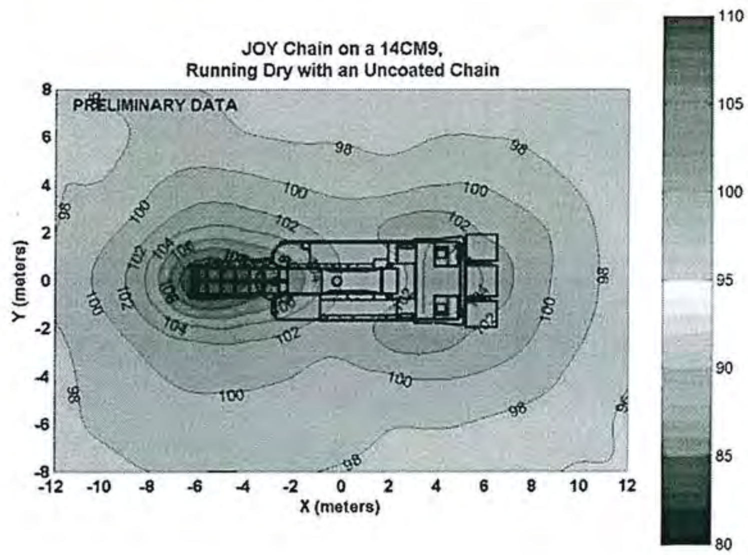

Illustration 3

SOUND PRESSURE MEASUREMENTS FOR JOY 14CM 9 MINER WITH ENGINEERING CONTROLS

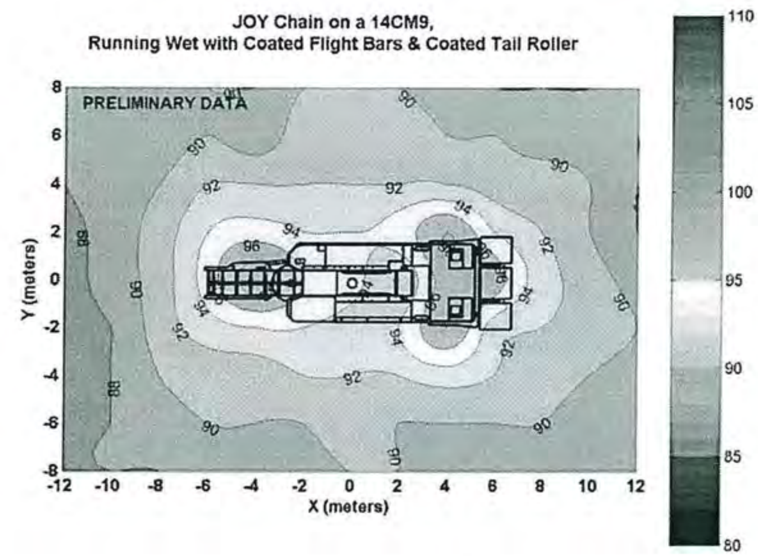

Illustration 4

Flights Coated With PO#650Urethane Coating After 62 Days

Illustration 5

Flights Coated with PO#652Urethane Coating After 62 Days

Illustration 6

Coated Tail Roller

Illustration 7

Coated Tail Roller After 21 Shifts

Illustration 8