A dual sprocket chain as a noise control for a continuous mining machine[1)]

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Over-exposure to noise remains a widespread, serious health hazard in the U.S. mining industry despite 25 years of regulation. Most other categories of illnesses and injuries associated with mining have improved, with the exception of hearing loss. In order to reduce cases of Noise Induced Hearing Loss (NIHL) in the mining industry, retrofit acoustic treatments and controls are being developed to subdue noise at the source. The Mine Safety and Health Administration (MSHA) coal noise sample data collected from 2000 to 2005 has determined that continuous mining machines rank first among all mining equipment whose operators exceed 100% noise dosage. The continuous mining machine conveyor, used to move coal from the cutting face to the rear of the machine, has been identified as a dominant noise source. A dual sprocket conveyor chain was tested as a potential solution. Sound power level measurements conducted at the Pittsburgh Research Laboratory (PRL) accredited reverberation chamber showed a 3 dB reduction in the A-weighted sound power level when the dual sprocket chain was implemented. Underground results show an 8-hour Time Weighted Average ($TWA_{8\ hrs}$) reduction a 3 dB for continuous mining machine operators. Utilizing this newly developed noise control, along with previously proven controls, provides continuous mining machine operators an opportunity to be within the MSHA-Permissible Exposure Limit (MSHA-PEL).

Primary subject classification: 14.3.2; Secondary subject classification: 62.1

1 INTRODUCTION

Hearing loss caused by exposure to occupational noise results in devastating hearing disability that is virtually 100 percent preventable. Occupational Noise-Induced Hearing Loss (NIHL) has been recognized by the National Occupational Research Agenda (NORA) as the most common job-related disease in the United States[1]. This health issue is particularly ubiquitous in the United States mining industry. “Hearing Loss or Impairment” accounted for 15% of the total reported cases of illness and disease in the mining industry for 2006[2]. An analysis of audiograms conducted by the National Institute for Occupational Safety and Health (NIOSH) shows that over half of the mining population sampled had a hearing impairment by the age of 50, while only 10% of those who are not exposed to occupational noise experienced a hearing loss by the same age[3,4].

Despite 25 years of regulation, overexposure to noise remains a widespread serious health hazard in the U.S. mining industry. In 1999, the Mine Safety and Health Administration (MSHA) altered its rules regarding noise exposure in an effort to reduce the incidence of NIHL[5]. Among other changes, the new regulations required mine operators to use all feasible engineering and/or administrative controls to reduce the noise exposure of overexposed miners. However, for many of the machines used in underground mining no noise controls exist to reduce worker exposure below the MSHA Permissible Exposure Level (PEL).

Due to the relatively large size of underground mining equipment, NIHL is common in the mining community. Comparing equipment used in underground coal mining operations, the Continuous Mining Machine (CMM) accounts for the most noise overex-

[1)] The finding and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute of Occupational Safety and Health.

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posures. Examination of the MSHA coal database shows that 65% of workers who were overexposed to noise operated one of seven types of equipment, of these the CMM produced the most noise overexposures to workers of all surveyed equipment[6]. NIOSH underground noise surveys have observed CMM sound pressure levels as high as 109 dB(A), and operator noise dose levels as high as 347%[7].

2 BACKGROUND

Underground mining methods are employed when coal deposits lie deep below the surface of the earth. Coal mine operations employs over 80,000 workers in the United States, and approximately 60% work underground[8]. There are two primary approaches that are used in underground coal mining: the longwall mining method and the continuous mining method. The longwall mining method utilizes a mechanized rotating shearer that moves back and forth across the coal face, which can be over 300 m wide. The continuous mining method utilizes a CMM to divide the mine into a series of 6-to-9 m "rooms" where work areas are cut into the coal seam and "pillars" are left behind for roof support. The longwall mining method is a more efficient means to extract coal, but is not applicable for all economic and geological situations. The continuous mining method accounted for 173 million tons of coal mined in the United States in 2007, just under half of the total underground coal produced[9]. This method of mining remains one of the fundamental methods to extract coal during mining operations, and the CMM is one of the primary machines used for this type of mining.

The CMM is used to remove product from the working face of underground mining operations. These machines were first introduced in the late 1940's and greatly improved the efficiency and speed of the mining process. The CMM has an armature attached to a rotating drum that is fitted with carbide Tungsten cutting bits, which gouge the mine face. Particulate matter created from the cutting process that is not suppressed by a water spray is collected by a vane-axial fan system, called a dust scrubber. The fractured pieces of mined material are scooped up by the gathering arms, which are located underneath the cutting head. Steel bars perpendicular to the conveyor chain, called flight bars, span the width of the conveyor and move the material to the rear of the machine. As the mined product is dumped off the end of the conveyor, the chain and flight bars traverse their path to the underside of the machine via the tail roller. The operator typically maneuvers the machine, by remote control, close to the end of the conveyor. Finally, the mined material is either picked up by a loader or dumped directly onto a shuttle car where it is hauled out of the mine for processing.

Overall noise generated by the CMM is a result of several operational system mechanisms. The cutting, dust collection, and conveying systems can be operated independently, but are often all running simultaneously during operation. The cutting system noise is a result of the interaction between the cutting bits on the rotating drum and the mine seam. The dust collection system noise is the result of the vane-axial fan used to collect fine particulate during cutting, which is usually located opposite of the operator. The conveying system noise is caused by impacts that occur between the conveyor deck and flight bars, used to move mined material to the discharge end of the machine.

Various research efforts have concentrated on reducing noise generated by CMM component systems. Treatments developed to reduce noise generated by the vane-axial fan in the dust scrubber have shown promise[10]. However, noise levels produced by the dust collection system are less than other component operations, which must be reduced first in order to obtain a reduction in overall CMM noise levels[11,12]. Past studies conducted by the Bureau of Mines (BOM) concentrated on the importance of noise associated with the cutting system[13]. However, this assumed that the operator controlled the continuous mining machine via on board controls, unlike the remote machine controls typically used by industry today. Through the use of remote controls operators are more directly exposed to the noise generated by the conveying system, which has been the focus of recent investigations[12,14].

Efforts to reduce the overall noise levels produced by the CMM must concentrate on engineering noise controls for the conveying system. Noise generated by the impacts that occur between chain flight bars and conveyor components is particularly severe where the chain traverses its path; at the gear sprocket (front of machine) and tail roller (rear of machine)[14,15]. Early research conducted by BOM concentrated on treatments to reduce CMM conveyor system noise[16]. Some of these treatments showed promise in the laboratory, but were never investigated for durability in an underground working environment. Recent studies have examined treatments at the tail roller component to reduce noise in this area due to the close proximity to the operator location[12,15,17]. However, recent research has shown that noise control treatments must also be considered at the gear sprocket area at the front of the machine.

3 APPROACH

A dual sprocket chain has been developed to address CMM conveyor system noise at the chain/sprocket

Fig. 1—CMM prototype dual sprocket chain (a) at the front foot shaft and single sprocket chain (b) at the rear tail roller.

Fig. 2—Joy Mining Machinery 12CM9 in PRL reverberation chamber.

interface. A conventional CMM uses a conveyor chain that is driven by a four or five tooth sprocket, depending on the chain manufacturer. Pictures of a Joy Mining Machinery[2)] conventional four tooth sprocket chain and a prototype dual sprocket chain used during laboratory testing are shown Fig. 1. The single sprocket chain consists of an 83 mm pitch chain with 433 mm length flight bars and a four tooth sprocket. The prototype dual sprocket chain is driven by two eight tooth sprockets that have the same pitch as the single sprocket chain. To accommodate for the extra sprocket, the conveyor flight bars on the dual sprocket chain have a shorter length of 370 mm. Both chains were driven at a measured speed of 2.4 m/s.

Acoustic evaluations were conducted in the laboratory and in an underground working environment. Original prototype versions of the dual sprocket chain were built by Joy Mining Machinery, and acoustic laboratory testing was performed at the NIOSH Pittsburgh Research Laboratory (PRL). Noise generated by various conveyor conditions was examined for each chain type. A modified Joy Mining Machinery 12CM-9 CMM was used during laboratory testing to examine both chain types, shown in Fig. 2. Later, a production version of the dual sprocket chain was manufactured and installed on a CMM in an underground coal mine. A similar model CMM with a single sprocket chain was used to collect baseline operator noise exposure. Task observations were also recorded to ensure that the CMM operator work shifts would be comparable.

Sound Power Level measurements were used to compare noise generated by the dual and single sprocket driven chains. These measurements were performed in the National Voluntary Laboratory Accreditation Program (NVLAP) reverberation chamber at PRL[18,19]. All sound power measurements were conducted in accordance with ISO 3743-2 using the comparison method with the equation:

$$L_W = L_{W_r} + (\bar{L}_P - \bar{L}_{P_r}) \qquad (1)$$

where L_W is the sound power level, $\bar{L}_P$ is the space-averaged sound pressure level, and the subscript "r" denotes the reference source. Fifteen microphone locations were used to create the parallelepiped measurement grid, and the sound pressure level data were collected with a Bruel & Kjaer Pulse acquisition system. The sound power level was calculated for each one-third octave band and these values were logarithmically summed to calculate an overall sound power level. If the dual sprocket demonstrated promise in the laboratory then the next step would be to conduct an underground field evaluation.

Underground field evaluations were utilized to determine the amount of acoustic noise that a CMM operator is exposed to during a work shift. Dosimetry was used to evaluate the underground noise exposures of CMM operators using single and dual sprocket conveyor chains. A Larson Davis Spark 703 personal noise dosimeter was used to collect worker exposure data. Dosimeter parameters were set according to MSHA specifications, which are displayed in Table 1. The microphone on the dosimeter was placed at the midpoint of the CMM operator's shoulder, with the microphone diaphragm pointing up. The dosimeter was installed and removed from the miner before and after the mine mantrip.

Exposure data were collected over four total days during two separate trips to the mine site. For both field

Table 1—Parameters used for dosimeters to monitor noise exposure.

Parameter	Setting	Designation
Weighting Function	A	MSHA Permissible Exposure Level (PEL)
Threshold Level	90 dB	
Exchange Rate	5 dB	
Criterion Level	90 dB	
Response	Slow	
Upper Limit	140 dB	

[2)]Mention of company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

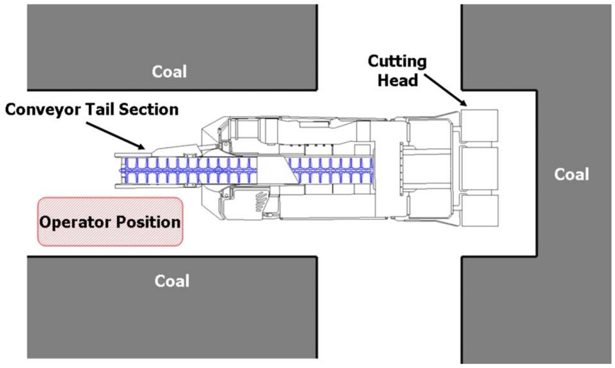

Fig. 3—Underground orientation of continuous mining machine.

visits, the dual sprocket and single sprocket chain were examined for a full work shift. On one day dosimetry data were collected on the standard chain and on the other day dosimetry data were collected on the dual sprocket chain. The same model CMM, Joy Mining Machinery 14CM-15, was used for all underground measurements. However, different operators were used because the underground tests were conducted over two days and the same operators were not available. Typical underground machine orientation and operator positioning is shown in Fig. 3. Note that the CMM operator uses a wireless remote control and would generally stand in the area shaded red. Time motion studies were also conducted each day to guarantee comparable machine usage. Operator noise exposure was calculated in accordance with ANSI S12.19 using the equations:

$$D = \left(\frac{100T}{T_c}\right) 2^{(L_i - L_c)/Q} \tag{2}$$

to calculate noise dose, and

$$L_{TWA(8)} = L_c + \frac{Q}{\log_{10}(2)} \log_{10}\left(\frac{D}{100}\right) \tag{3}$$

to calculate the eight-hour time-weighted average sound level. In Eqn. (3), D is the noise dose, T is the measurement duration, T_c is the criterion duration, L_i is the A-weighted sound pressure level, L_c is the criterion level, Q is the exchange rate, and $L_{TWA(8)}$ is the eight-hour time-weighted average sound level.

4 RESULTS

Acoustic measurements made in the laboratory allowed various machine conditions to be examined. In order to place the mined product in strategic locations, the CMM has the ability to articulate its conveyor tail section. Three CMM conveyor conditions (left, straight, and right) for each chain type were examined as shown in Fig. 4. The one-third octave band results of

Fig. 4—CMM conveyor configurations: left, straight, right.

the A-weighted sound power level testing with the tail section straight is shown in Fig. 5. The results shown in Fig. 6 and Fig. 7 show the A-weighted sound power levels for the tail section swung fully to the right and left, respectively. The solid black lines in Figs. 5–7 depict levels for the single sprocket chain and the grey lines represent levels for the dual sprocket chain. The overall A-weighted sound power levels for each test condition are summarized in Table 2.

By examining the sound power level measurements, important observations can be made about how CMM noise is generated. For the single sprocket chain with the tail straight shown in Fig. 4, over 90% of the A-weighted sound power generated occurs between

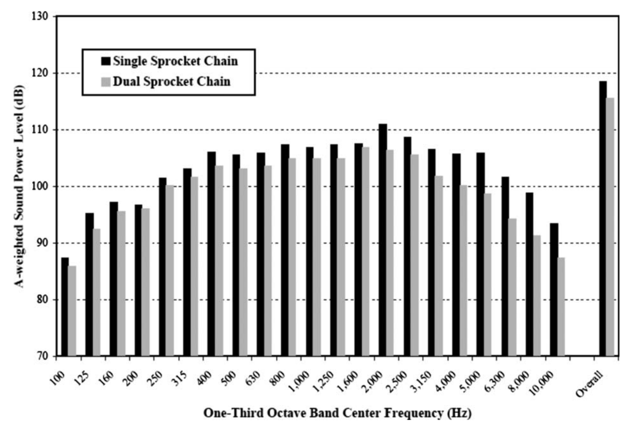

Fig. 5—Sound power level comparison with the CMM tail section straight.

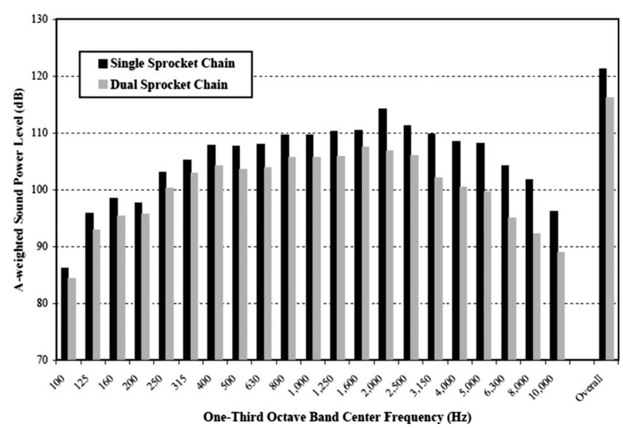

Fig. 6—Sound power level comparison with the CMM tail section swung right.

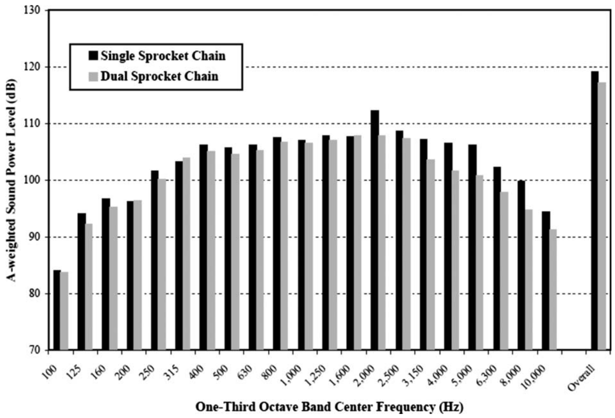

Fig. 7—Sound power level comparison with the CMM tail section swung left.

400 Hz−5 kHz. The same general trend occurs when the tail section is swung to the right and left in Fig. 6 and Fig. 7. The highest individual one-third octave band level for all three test conditions occurred at 2 kHz. Reductions are observed in most one-third octave band frequencies when the dual sprocket chain was installed, with the most significant reductions occurring at frequencies above 2 kHz.

The field evaluation was conducted in an underground coal mine in western Kentucky to examine worker noise exposure. Two of the same model machines (Joy Mining Machine 14CM-15) were used; one with the dual sprocket chain installed and the other with a standard single sprocket chain. The mine seam height was approximately 2.5 m high and entries were 2 m wide by 5 m long. Underground CMM coal production was around 2.7 KT for each shift that was observed. The CMM operator accumulated noise dose for each underground field evaluation is shown in Fig. 8 and Fig. 9. The solid line indicates a work shift where the operator used the machine with a standard single sprocket chain, and the dashed line designates a work shift where the dual sprocket machine was used. Basic CMM operator task observation are also displayed in Fig. 8 and Fig. 9 showing the relative time spent doing a particular operation. The end of shift operator noise exposure results for both underground field trips are summarized in Table 3.

Table 2—Overall results of sound power level tests in reverberation chamber.

Conveyor Orientation	Single Sprocket Chain	Dual Sprocket Chain
Conveyor Straight	118.5 dB(A)	115.5 dB(A)
Conveyor Right	121.2 dB(A)	116.2 dB(A)
Conveyor Left	119.1 dB(A)	117.1 dB(A)

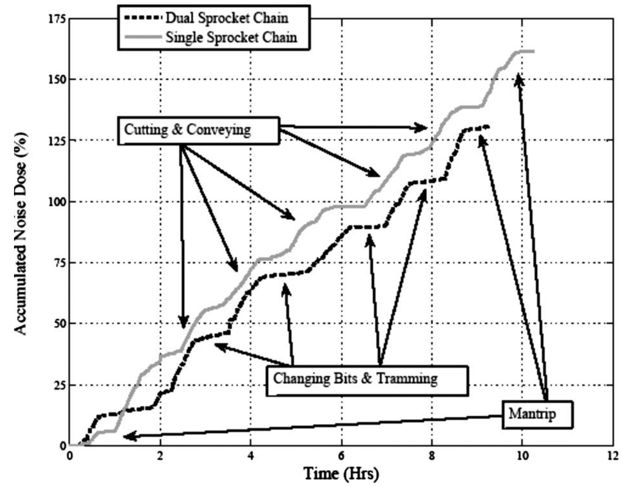

Fig. 8—CMM Underground Operator Noise Exposure for Trip 1.

Underground noise dosimetry data shows how miners are exposed to CMM noise. While comparing chains in Fig. 8 and Fig. 9, it can be seen that the continuous mining machine operator experienced a generally uniform dose accumulation throughout the shift with occasional periods of low exposure as shown

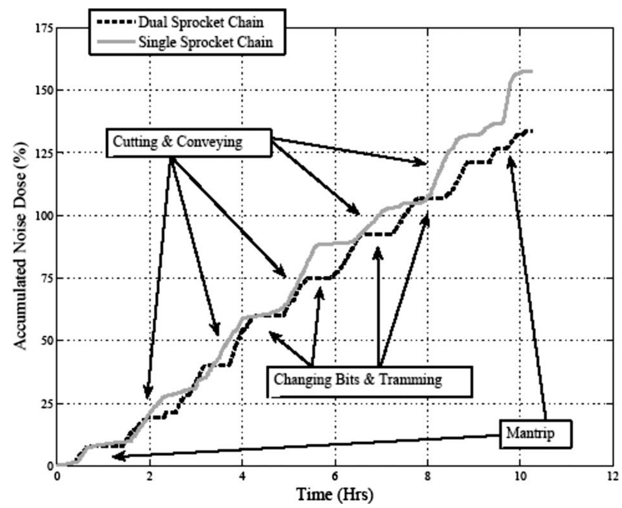

Fig. 9—CMM Underground Operator Noise Exposure for Trip 2.

Table 3—Underground CMM noise exposure results.

Chain Type	Trip	Work Shift Length	Accumulated Noise Dose	$TWA_{(8\ hrs)}$
Single Sprocket Chain	1	10.3 Hrs	161%	93.4 dBA
	2	10.3 Hrs	157%	93.3 dBA
Dual Sprocket Chain	1	9.3 Hrs	131%	91.9 dBA
	2	10.3 Hrs	134%	92.1 dBA

by the flat slopes of the cumulative dose line. These low dose periods occurred when the worker was changing cutting bits or when the CMM was tramming. Further observations revealed that less dose accumulation occurred when the miner was in the man trip. High dose periods occurred when the continuous mining machine was cutting and conveying. It should also be noted that the conveyor was continuously running during all the high dose periods. Exposure levels with the standard chain were relatively consistent with levels of 157% for survey one and 161% for survey two. The dual sprocket machine exposure levels were 130% for survey one and 133% for survey two, which were consistently lower. This resulted in a 8 hour Time Weighed Average (TWA) reduction of over 1.2 dB(A) for trip 1, and 1.5 dB(A) for trip 2.

5 DISCUSSION

Results of laboratory testing conducted in the PRL reverberation chamber were examined to determine if the dual sprocket chain was a feasible noise control. Noise generated by the conveyor system was on average 3 dB(A) less when the dual sprocket chain was installed during laboratory evaluations. A standard CMM conveyor chain is driven by a four or five tooth sprocket gear, which can cause impacts to occur at the front of the machine and interference with the Continuous Loading Arms (CLA). The dual sprocket chain provides a smooth transition at the drive shaft that reduces impacts and interference with the CLA. Also, tension is kept more uniform due to the contestant contact between the chain and 16 sprocket teeth.

Chain tension is an important variable when examining noise generated by the CMM conveyor system. The A-weighted sound power generated by the dual sprocket was 3 dB less than the standard chain when the conveyor was in the straight position. However, when the conveyor was extended fully to the right the dual sprocket displayed a 5 dB reduction and only 2 dB in the A-weighted sound power level when extended fully left. These differences were most likely the result of different chain tensions due to the coil spring take-up system. As per the chain manufacturer specifications, chain tension could only be verified when the tail section was in the straight position[15] during laboratory testing. The coil spring take-up system was replaced with a hydraulic cylinder that provided uniform tension when the conveyor was swung to the left and right during underground evaluations.

The underground operation of the continuous mining machine is subjected to many variables that can affect the noise emissions. Some of these variables, such as the acoustic environment, geometry and composition of the surfaces, mine geometry, and compressive strength of the face media, can not be controlled. The compressive strength of the face media being cut affects the acoustic absorptive properties of the mine environment. Harder media, with compressive strengths above 140 MPa, reflect more acoustic energy than softer media, i.e. less than 70 MPa compressive strength. The operator who is responsible for controlling the CMM can also influence the overall noise level generated. All of these variables need to be considered when conducting underground field evaluations.

6 CONCLUSION

A dual sprocket conveyor chain for a CMM was examined both in the laboratory and in underground field studies. Laboratory results show that the dual sprocket chain has a significant influence on lowering the sound power emissions of the chain conveyor of a CMM when compared to a standard chain. The underground results were not as significant for the dual sprocket chain as in the laboratory, but did show a reduction in noise exposure to the operator. From the time motion study it was noted that there were several variables that could have influenced the results. Some of these were difficult to control such as the face media when cutting (different compressive strength), different operators, chain tension on the standard chain, and different sections of the mine. However, it is believed that the dual sprocket chain could be an effective noise control if used with another noise control; such as urethane coated flight bars[12,15,16].

In general, experimental results show that the dual sprocket chain has potential and if used in conjunction with other noise controls could be effective. However, implementing a dual sprocket chain on a CMM that is close to the MSHA-PEL may bring the operator within compliance with federal regulations. Utilizing this noise control on a CMM will reduce the noise generated at the front (gathering end) of the machine. If noise produced by other CMM conveyor components is reduced through engineering controls, the dual sprocket chain could have a greater impact on noise reductions. Using a dual sprocket conveyor chain in combination or as part of a suite of noise controls will reduce noise generated by the CMM, and reduce the occurrence of noise overexposures in the mining industry.

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