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Noise Variability in Underground Room and Pillar Coal Mines

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Noise in an underground coal mine has dominant components generated mainly from 3 sources: (a) continuous mining machines, (b) roof bolters, and (c) cars/vehicles used to transport personnel and/or coal. Each of these 3 noise sources also has a number of well-defined sub-sources with their own noise characteristics. Sound level meters were used to collect noise data in the form of instantaneous readings and also to check calibration of other sound measuring instruments. The most useful information was obtained from a spectrum analysis of continuous digital recordings of noise over time. This paper discusses the variability or dynamics of generated noise in both frequency and time domains in relation to several independent variables related to coal extraction and transportation processes.

underground noise control   noise measurements   noise-induced hearing loss

1. INTRODUCTION

In underground coal mines, noise is defined as unwanted sound and is considered to be one of the adverse environmental factors, which include unwanted vibrations, air pollution (especially dust), chemical vapors/gasses, and air drafts. Exposure to elevated noise levels (where time is also a major factor) can cause not only noise-induced hearing loss (NIHL), but also physical and physiological stress, fatigue, cardiac abnormalities, and other health concerns. NIHL is recognized as an occupational illness caused by long-term exposure to excessive sound levels. Currently, the Mine Safety and Health Administration defines permissible noise levels and provides for the use of "engineering and administrative controls to reduce the miner's exposure to as low a level as is feasible" (p. 4959) [1]. Noise standards established by the U.S. Mine Safety and Health Administration (MSHA) set the noise exposure level for miners at a time-weighted average of 85 dB(*A*) (determined using the *A* frequency weighting curve) for an 8-h exposure. At higher noise levels, the exposure time must be decreased. No employee can be exposed to steady noise levels above 115 dB(*A*) regardless of their duration, and impact or impulsive noise above 140 dB peak.

The *A* frequency weighting curve is used most often to evaluate noise levels as it conforms approximately to the response of the human ear especially for low or moderate amplitudes of

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sound. The *C* frequency weighting curve, which is relatively flat over a wide frequency range is also used, particularly when evaluating loud (above 85 dB) or low-frequency (below 200 Hz) noise. Since the difference between sound pressure level (SPL) measurements performed using *A*- and *C*-weighted characteristics reaches 20 dB (corresponding to a 100-fold change in sound pressure value) at 100 Hz, noise information in the low-frequency range measured using the *A*-weighted curve can be distorted. This property is used to detect the content of low-frequency noise (LFN) in a measured frequency spectrum. For example, it was observed that during normal operation of the continuous mining machine's (CMM) coal excavating drums in interaction with the coal seam and surrounding rock, a large amount of LFN was generated. It was desirable to measure and record noise in amplitude form versus frequency (as a frequency spectrum) using *C*-weighted curves and determine MSHA compliance by extracting SPL values in *A*-weighted decibels from that signal [2].

To reduce noise in mining environments, Joy Mining Machinery (JOY) developed the quiet tail continuous miner (QT-CM). Sound treatments on the QT-CM included an improved tail cam system and hydraulic chain tensioning device, improved chain return path, modified chain deflector, and a dual chain driven with an 8-tooth sprocket. Earlier versions of the QT-CM were tested by the National Institute for Occupational Safety and Health (NIOSH) at the Pittsburgh Research Laboratory and in underground mine production environments. Results were promising with an 8-h average noise exposure reduction of 3 dB(*A*) [3]. This paper reports on an investigation that took place at Peabody's Willow Lake Mine in southern Illinois where a standard JOY CMM was modified in 2008 by replacing the single-strand conveyor chain and associated sprocket with a double-strand chain and an 8-tooth sprocket. The chain tensioning system and deflecting plates were also modified. In-mine measurements indicated that acoustical energy from the CMM with design modifications was approximately two times lower in comparison with noise generated by a standard CMM with a single-strand conveyor chain. These results were almost identical to those of the NIOSH laboratory study referenced earlier. From a productivity perspective, time studies of the mining sequence showed no significant difference in loading times for the two machines.

2. EXPERIMENTAL PROCEDURES

SPL measurements for different equipment were identified with equipment location, mine opening geometry, and mining activity. They were performed at the location defined as the operator position. Noise variability during haulage unit loading as well as other operations like drilling, bolting, and coal transporting with haulage equipment were also measured and recorded as digital files. The complex CMM noise spectrum is comprised mostly of noise generated by three individual sources: front cutting head, dust collector system, and chain conveyor [4]. The hydraulic system also adds a distinct noise spectrum, but it is very low in comparison to the other three. Noise levels associated with CMM operations, including those generated by each individual source, were recorded using a digital linear PCM-D50 (Sony, Japan) recorder in controlled non-production and production situations in typical acoustical mine environments. Average time-weighted SPL values were extracted from recordings with Brüel & Kjær (Denmark) spectrum analyzers and evaluated for frequency, amplitude, and variability with time in correlation with mining operations and the mine environment. SPL measurements were also made on roof bolters, haulage units, and feeder-breakers.

3. RESULTS

Each individual noise source on the CMM, roof bolter, or haulage unit generates its own spectrum of noise that interferes with other noise and with the geometrical configuration of the mine opening, presenting complex equivalent noise characteristics. The opening acts as a semi-reverberant cavity with noise traveling away from the sources through only a few distinctive paths. The first one is the mine opening itself where noise travels in the air, subjected to frequent reflections and changes of direction. Attenuation of the noise energy in this path is relatively low. The second path is the ribs, roof, and floor of the mine opening and human-made partitions (called stoppings) built in some openings, where noise attenuation due to large transmission losses (in the solid) is much higher than in an air path. There is also a third path of noise emerging from the solid, which is the weakest one. Absorption of noise energy in this environment is relatively low. Noise waves in these paths interfere with each other and mine personnel are exposed to that equivalent noise. Very annoying LFN with an amplitude of 85 dB(*C*), which can be described as a flutter or rambling noise, was observed at a distance of ~50 m from the working CMM where the typically wide noise spectrum had been modulated with a very strong low frequency (1–5 Hz) signal.

3.1. Continuous Mining Machine Noise Studies

Variability of SPL in time (dynamics) was observed in every cycle of the car loading process (Table 1). At the beginning of the loading process, the conveyor was typically empty. Thus, noise damping and lubrication providing by wet coal was absent leading to elevated noise levels. This elevated noise phase at the beginning (B in Table 1) of the loading process comprised 8% of the total time it took to load one ram-car. The lowest SPL readings occurred at the end (E) of the loading process, which comprised 14% of total loading time for one ram-car. The remaining 78% of total loading time was the middle (M) period, which was characterized by relatively steady SPL noise readings.

The discharge end of the CMM conveyor (tail) can be swung a maximum of 30° to either side of the CMM center axis. When the conveyor is so positioned to the left or right, as conveyor flights go around the bend that is created in the tail boom, they contact flexible steel deflector plates positioned in the bend to keep coal on the conveyor. This leads to increased noise levels due to elevated amplitudes over a wide band of the frequency range generated by metal-on-metal impact.

The highest noise level was observed when both of these conditions (beginning of the loading process and conveyor swung to the side) were applied. The difference line in Table 1 shows that the CMM with the double-strand chain was significantly less noisy than the CMM with the single sprocket and single-strand chain in similar working conditions. Although difficult to quantify, it was observed that elevated SPL readings occurred when the CMM cutting head encountered rock, either above, below, or within the coal seam.

Figures 1–3 provide visual images of the CMM noise frequency spectrum. These charts show distinctions between the beginning, middle, and end of the loading cycle as well as when the CMM tail was swung to the left or right generating more impact noise. The *C*-weighted frequency curve used in this analysis made it possible to measure LFN characteristic of the mining environment. In every conveyor position and loading phase, the maximum noise level

TABLE 1. Comparison of Average Sound Pressure Level (SPL), in *A*-Weighted Decibels, for Continuous Mining Machines During a Typical Loading Process

	Conveyor								
	Straight			Right			Left		
Average SPL	**B**	**M**	**E**	**B**	**M**	**E**	**B**	**M**	**E**
Single-strand chain	97.7	96.7	94.3	103.2	97.7	96.1	102.7	97.4	96.3
Double-strand chain	95.9	92.1	90.6	97.2	94.5	91.6	96.9	94.7	91.8
difference	1.8	4.6	3.7	6.0	3.2	4.5	5.8	2.7	4.5

Notes. B, M, E—loading stages (beginning, middle, end).

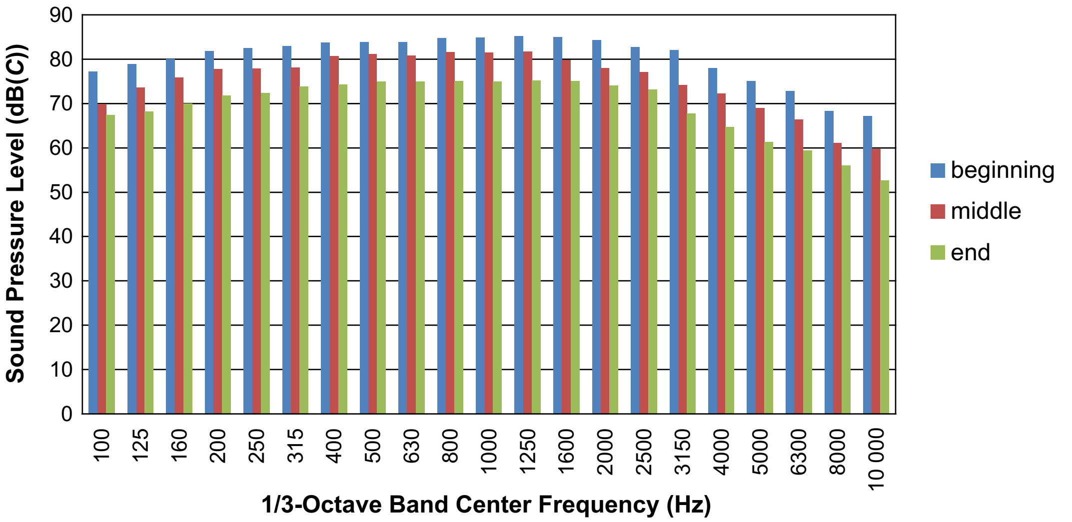

Figure 1. Noise spectrum generated by a continuous mining machine in average working conditions with the double-strand chain conveyor in a straight position.

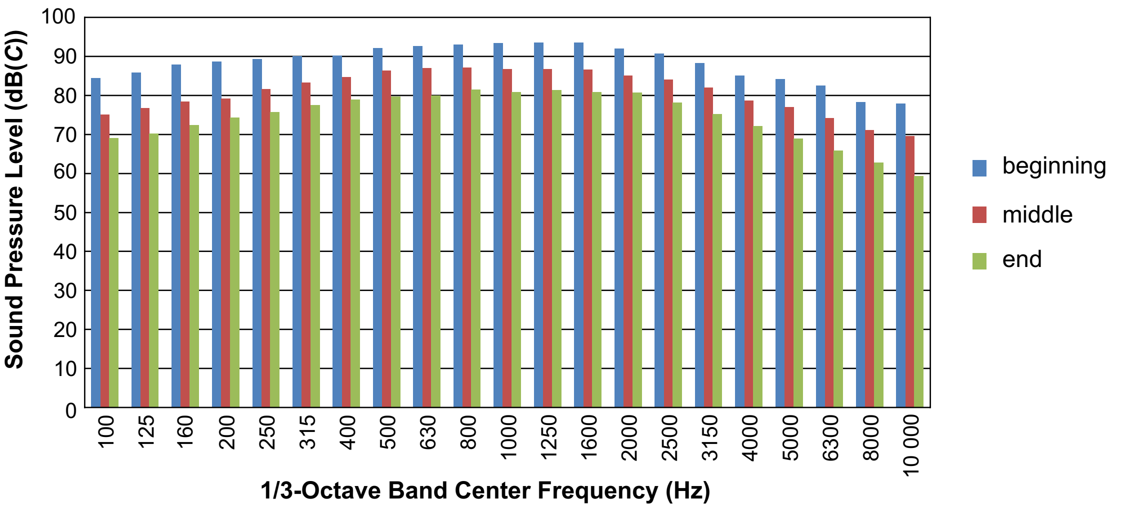

Figure 2. Noise spectrum generated by a continuous mining machine in average working conditions with the double-strand chain conveyor swung to the right.

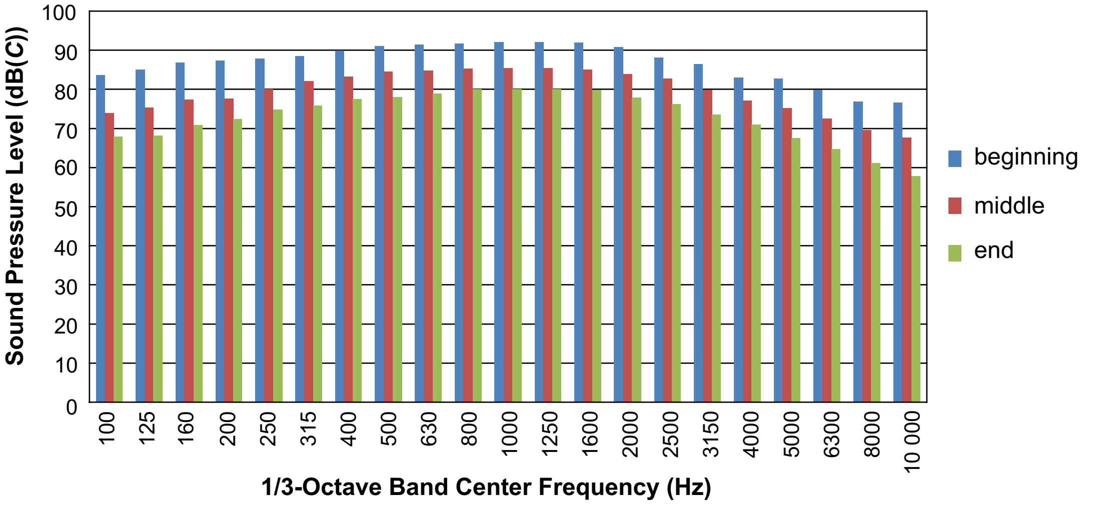

Figure 3. Noise spectrum generated by a continuous mining machine in average working conditions with the double-strand chain conveyor swung to the left.

generated by the CMM was in the range between 500 and 1600 Hz with the most significant level of noise generated between 400 and 4000 Hz.

To break down the individual noise sources on the CMM, a digital recording was made with the CMM backed away from the face into an intersection with an open crosscut. The miner

TABLE 2. Recorded 1/3-Octave Sound Pressure Level, in *C*-Weighted Decibels, of Each Continuous Mining Machine Noise Source Without Cutting or Transporting Coal

	Sound Pressure Level					
				Conveyor		
Frequency (Hz)	Hydraulics	Cutting Drum	Dust Collector	Right	Left	Straight
100	61.1	76.1	86.3	94.1	93.6	88.5
125	63.0	78.3	87.8	94.0	93.1	88.3
160	69.8	81.4	84.5	92.9	91.2	87.9
200	71.3	83.7	84.9	94.9	93.3	90.4
250	72.6	85.0	85.6	96.1	95.2	91.7
315	83.0	86.9	88.7	94.7	98.9	91.5
400	60.9	88.2	90.1	98.2	95.5	92.8
500	61.3	89.9	91.4	98.6	95.6	93.3
630	67.0	91.3	89.9	99.9	98.3	96.8
800	58.4	91.5	91.6	100.5	98.8	97.1
1000	61.2	90.2	90.7	100.7	99.1	97.5
1250	56.5	89.4	87.4	101.0	100.1	96.9
1600	58.3	85.7	86.3	100.2	98.9	96.2
2000	56.4	80.6	86.0	99.7	99.1	94.5
2500	52.7	76.3	84.2	98.6	97.7	93.6
3150	54.5	71.1	78.1	97.3	96.2	91.7
4000	53.4	63.9	75.4	95.9	94.3	87.4
5000	49.8	58.5	73.5	92.7	92.1	83.8
6300	52.3	54.7	71.8	86.8	84.9	78.5
8000	49.2	51.5	69.6	79.5	78.2	69.3
10 000	49.3	51.2	68.9	76.3	76.1	67.9

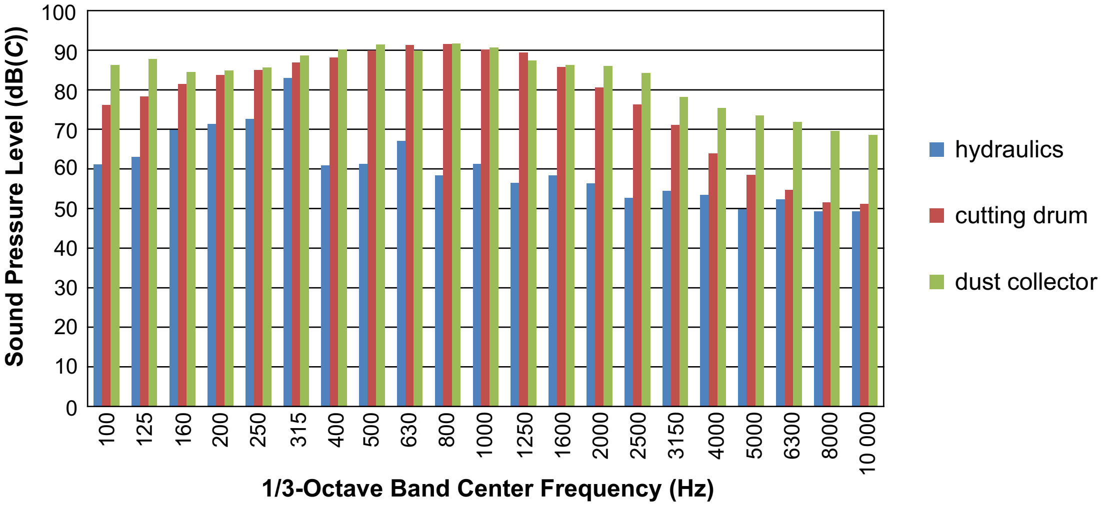

Figure 4. Noise spectrum generated by a hydraulic system, a cutting drum, and a dust collector with a continuous mining machine not mining coal.

operator turned on each component of the CMM and let it run without producing any coal while the recording was made. Table 2 lists recorded noise levels for each noise source. With no coal on the conveyor, its noise level was significantly elevated. Figure 4 shows the frequency spectra generated by the CMM hydraulic system, the CMM cutting drum rotating freely, and the CMM dust collector (scrubber). The noise spectrum generated by the dust collector was independent of other noise sources and working conditions and did not vary in time. The noise generated by the hydraulic system varied with the horizontal position of the conveyor and the vertical position of the cutting drum. Also, the QT conveyor model used a hydraulically controlled chain tensioning mechanism, which influenced the amplitude of noise generated by the hydraulic system. With the conveyor empty, metal-on-metal impact noise was clearly audible when the tail was operated out of the central axis position.

3.2. Roof Bolter and Haulage Unit Noise Studies

Noise generated by pass-by ram-cars and the roof bolter drilling holes and tightening bolts was also digitally recorded and analyzed (Table 3). These data were collected over a long period with a large number of ram-car pass-by cycles and later averaged. The maximum amplitude of noise generated by battery-powered pass-by ram-cars was ~630 Hz. The amplitude depended mostly on operating conditions like coal payload and style of driving. The maximum amplitude of noise generated by the roof bolter in the drilling phase was ~800 Hz.

Data obtained with a hand-held SPL meter in dB(*A*)-slow mode indicate that noise levels generated by the roof bolter in drilling mode are at the level of noise generated by a working CMM, reaching 96.5 dB(*A*). Bolt tightening is almost as noisy, with SPL readings reaching 90.8 dB(*A*). These are identical to data extracted from simultaneously recorded digital files.

TABLE 3. Average Noise Spectrum Generated by Ram-Car and Roof Bolter

1/3-Octave Frequency Band (Hz)	Average Sound Pressure Level (dB(C))		
	Haulage Unit	Roof Bolter (Drilling)	Roof Bolter (Bolt Tightening)
100	71.3	72.1	74.6
125	74.1	73.0	75.2
160	77.8	73.1	77.0
200	83.9	73.2	77.9
250	82.5	73.2	80.0
315	87.6	74.7	81.2
400	87.1	77.5	82.2
500	87.2	82.1	84.0
630	88.1	85.1	85.1
800	85.0	88.0	84.8
1000	84.3	87.7	83.8
1250	84.6	87.5	80.0
1600	85.9	85.9	78.1
2000	87.1	83.9	76.9
2500	85.8	81.9	75.6
3150	80.0	80.8	75.0
4000	75.1	80.0	74.5
5000	70.2	78.5	73.1
6300	65.3	78.1	72.3
8000	61.2	77.5	68.0
10 000	56.3	77.5	64.7

4. CONCLUSIONS

Noise exposure is reduced with alterations in engineering design and equipment operation, reduced time of exposure, and hearing protectors. The most desirable of these is the first one, i.e., using engineering principles to reduce noise level. To evaluate the level of noise reduction achieved, the following noise-related components are considered: (a) sources of noise, (b) paths along which the noise travels, and (c) receivers (people) exposed to that noise. The enhanced engineering design evaluated in this project is a restructured chain conveyor system for a JOY CMM where a double-strand chain and modernized mechanical and hydraulic tensioning components replace the conventional single-strand chain and its associated components. The sound pressure generated by a CMM with a double-strand chain in a redesigned conveyor structure was approximately twofold lower in comparison with a single-strand CMM conveyor operating in the same conditions. This reduction of acoustical sound pressure corresponds to SPL lower by ~3 dB(*A*) at the operator's position. That reduction is entirely attributable to the redesigned conveyor system because noise generated by coal extracting heads and dust collectors did not change.

During the ram-car loading process, noise level variability in time (noise dynamics) was observed. In most cases, noise was elevated to or near its highest levels at the beginning of the loading process. This was caused by uneven distribution of stress on the chain itself and not enough deposition of coal on the conveyor to properly lubricate and dampen moving parts. The proper approach can be having efficient deposition of coal on the conveyor before restarting its operation. This can lower those elevated noise levels at the beginning of the loading process. Another noise reduction technique serves a dual purpose. Adding water at the point of extraction (near the cutter head and bits) and to the path of transported coal not only reduced generated noise, but also the amount of dust in the air. This study showed that the CMM cutter head interacting with the coal seam, using considerable force to extract and move coal (and sometimes the rock above and below it), generated a large amount of LFN. LFN can be measured by applying the *C* instead of the *A* frequency weighting curve.

Often, due to excavating conditions, the ram-car was positioned to the left or to the right of the CMM's center axis forcing the operator to adjust the position of the conveyor tail in a horizontal plane. In these conditions, swinging the conveyor tail to either side generated continuously elevated noise levels with significant amounts of acoustical energy in a wide frequency range caused by frequent impact noise (beating) from conveyor flights striking one of the flex plates that keep coal on the conveyor and channel it to the tail of the machine.

Noise treatment can be applied to roof bolters and haulage units as well, both of which were evaluated as part of this study. Roof bolters generated their highest level of noise during the drilling phase. The hardness of the rock being drilled significantly influenced the level of noise generated during drilling. The haulage units evaluated were battery-powered ram-cars which generated noise by way of their electromechanically powered drive train. Haulage unit noise levels depended on how much payload was being hauled and the operator's style of driving.

These data are useful for administrative and equipment operating personnel to properly schedule and control coal extraction and transportation processes for minimizing noise exposure. These data are also being used by manufacturers of CMMs, roof bolters, and transportation vehicles to modify existing equipment or design new equipment with lower noise generation.

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