Horizontal Vibrating Screens: Noise in Coal Preparation Plants, Dominant Noise Sources, and Noise Controls

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ABSTRACT

Sound levels in coal preparation plants often exceed 90 dB(A) and workers who spend a significant portion of their work shift in a preparation plant can be overexposed to noise. The National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) has studied horizontal vibrating screens as a noise source in coal preparation plants. Contour maps of the in-plant sound levels show that vibrating screens are a significant noise source within the plants. The sound levels around vibrating screens in use often exceed 95 dB(A). NIOSH OMSHR determined that the majority of the noise generated by screens during their operation is due to drive noise rather than material flow. In laboratory testing, NIOSH OMSHR identified the screen body, vibration mechanism housings, and steel coil springs as the most significant sources of screen noise using a technique known as beamforming. Several trial noise controls were developed and tested to address each of these noise sources. Laboratory measurements in the NIOSH OMSHR reverberation chamber show that installing a mechanism enclosure, applying constrained layer damping treatments to the mechanism housings, installing a mechanism suspension, and inserting rubber spacers between the steel coil springs reduced the sound power level generated by 6 dB(A).

INTRODUCTION

Noise exposure is a significant concern in the mining industry. According to Mine Safety and Health Administration (MSHA) data, 1,170 noise-related injuries have been reported in mining since 2000. Three hundred fifty-five of these cases (30% of all noise-related injuries) involve preparation plant employees (MSHA 2010). To determine worker noise exposure, MSHA uses a Permissible Exposure Level (PEL) of 90 dB(A) time-weighted average sound level for an 8-hour workday with a 5-dB exchange rate (Federal Register 1999). National Institute for Occupational Safety and Health (NIOSH) data from 1999 to 2004 show that 20 out of 46 coal preparation plant workers had noise exposures that exceeded the MSHA PEL for noise (Bauer 2004). MSHA PEL noise doses up to 220% have been recorded for preparation plant workers such as stationary equipment operators, froth cell operators, plant operators, plant controls men, third floor operators, wet plant attendants, sump floor operators, plant backups, and plant mechanics. These job classifications require the worker to spend a significant portion of a shift in the plant while working around slurry pumps, dryers, centrifuges, and vibrating screens.

Vibrating screens generate sound levels from 90 to 95 dB(A) during clean bituminous coal processing, and from 95 to 100 dB(A) during refuse and anthracite processing (Ungar et al. 1974). Since screens are used to size, separate, and dewater both coal and refuse (rock) of various sizes, they may be located on multiple floors within a preparation plant. The number of screens in a processing plant can range from a single screen to more than a dozen. Consequently, preparation plant workers can be exposed to screen noise many times during a workday. Vibrating screens are a major noise problem in coal preparation plants because screens are used extensively in the plants, are usually located in high traffic areas, and can generate high sound levels (Rubin et al. 1982).

The noise radiated by a screen is primarily due to two noise sources: screening noise and drive noise (Hennings 1980). Screening noise consists of the noise generated by the flow of the coal/water mixture down the chute and across the top of the screen deck. As the mixture flows out of the chute and across the screen, impacts between individual pieces of coal and between the mixture and the chutes and screen generate noise. Drive noise refers to the noise radiated due to vibration of the mechanism housings, screen sides, and the building, resulting from excitation by the gears, bearings, and eccentric weights of the mechanisms. Generally, screening noise is more significant than drive noise for coarse coal screens, while drive noise is dominant for fine coal screens (Ungar et al. 1976). For drain and rinse screens, such as the test screen in this study, the spray of rinse water onto the processed coal is another potential noise source.

NIOSH OMSHR measured the sound levels around a group of eight 2.44-meter by 4.88-meter horizontal vibrating screens in a coal preparation plant (Yantek et al. 2005). The screens were used to drain and rinse a 1 x 10 mesh cyclone clean coal product. Each of the screens was driven by dual vibration mechanisms operating at 900 RPM. The sound levels around the screens were found to range from 90 to 98 dB(A). Because the sound levels decreased with distance from the center of the screens, it is likely that the screens were the dominant noise source in this area of the preparation plant.

Since the revised Health Standard for Occupational Noise Exposure, 30 CFR Part 62, was passed in 1999, MSHA no longer gives credit for hearing protection in determining a worker’s noise dose (Federal Register 1999). This MSHA regulation has reemphasized the use of noise controls to reduce worker noise exposure. To be effective at reducing noise due to screens, noise controls must be developed for dominant noise sources on the screens.

Identifying noise sources and developing noise controls that address dominant noise sources requires a significant effort. This paper will discuss the identification of dominant noise sources on a horizontal vibrating screen using in-plant sound level measurements and laboratory beamforming measurements. In addition, several noise controls and their effect on the noise generated by a screen will be discussed.

COAL PREPARATION PLANT SOUND LEVEL MEASUREMENTS TO DETERMINE MAJOR CONTRIBUTORS TO SCREEN NOISE

To determine the major contributors to screen noise in a coal preparation plant, NIOSH OMSHR measured sound levels around one screen that was in a group of eight 2.44-meter by 4.88-meter horizontal vibrating screens used to drain and rinse a 1 x 10 mesh cyclone clean coal product (Yantek et al., 2005). Each of the screens was driven by dual vibration mechanisms operating at 900 RPM. Barrier-absorber material was used to minimize the background noise around the test screen so that the major contributors to screen noise could be determined.

Test procedures – determination of major contributors to in-plant screen noise

Screen #169 (refer to Figure 1) was selected as the test screen due to its location in the corner of the plant. To isolate the test screen from the airborne noise generated by the nearby screens and other equipment, a quilted barrier-absorber curtain consisting of two fiberglass layers with a loaded vinyl septum and covered in a nylon material was suspended from the bottom of the floor above the test area using bolts and grommets (refer to Figure 2). The barriers were sized such that they touched the floor when installed. The seams between individual barrier strips were sealed with hook and loop fasteners, and gaps around pipe penetrations were kept to a minimum. The above steps were necessary to reduce the background noise near the test screen as much as possible.

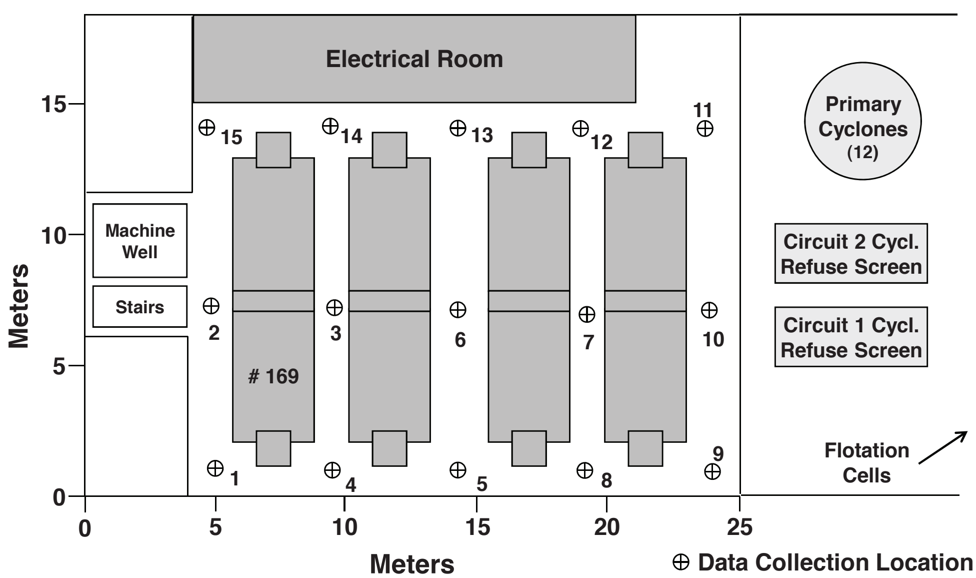


Figure 1.
Sound level measurement locations around a group of eight horizontal vibrating screens.

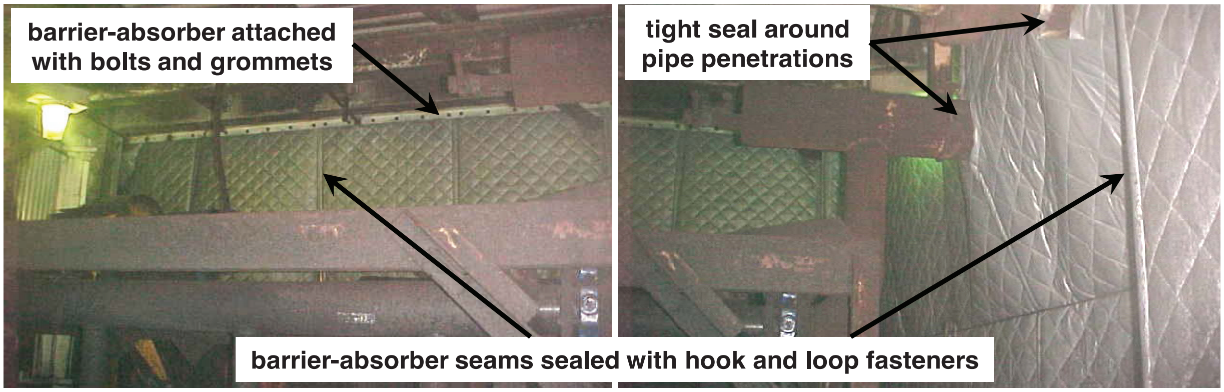


Figure 2.
Barrier-absorber panels used to reduce airborne background noise around the test screen.

Six Bruel & Kjaer 4188 microphones were positioned at a height of 1.5 meters and a distance of 0.61 meters from a reference box surrounding the test screen (see Figure 3). Four microphones were positioned along the left side of the test screen with two microphones behind the feed chute. Due to the proximity of the barrier to the right side of the test screen, it was not possible to position microphones along the right side of the screen.

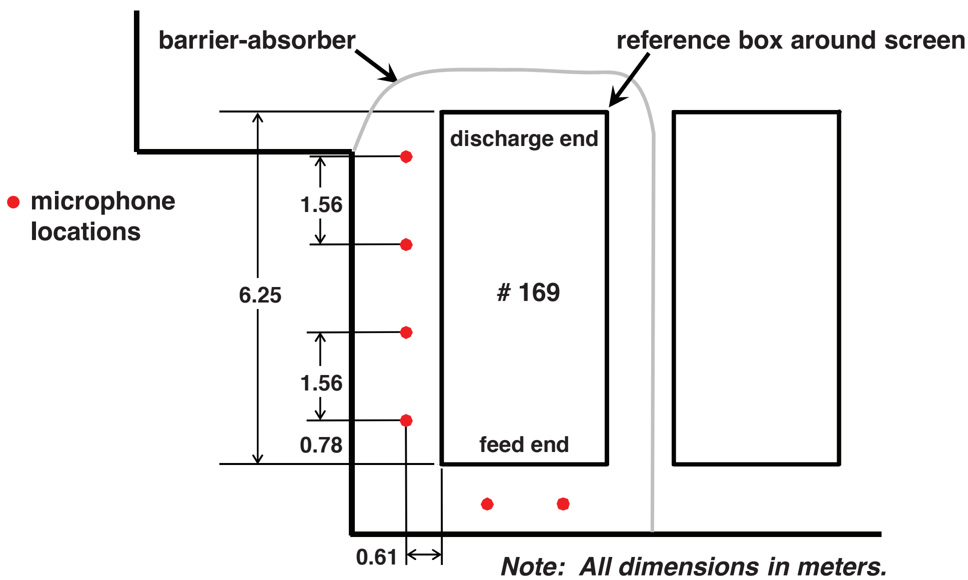


Figure 3.
Barrier-absorber location and microphone locations around the test screen.

Due to the design of the plant, it was not possible to process coal on only the test screen with the other screens turned off. However, it was possible to shut the test screen off while processing coal on the remaining seven screens. In addition, it was possible to operate the test screen in "vibration only" mode with the other screens turned off. Under these conditions, a series of tests were performed to determine the background noise around the test screen before and after the barrier-absorber was installed, the sound level with the screen operating in normal operating conditions (processing coal), the sound level with the test screen operating in "vibration only" mode with all other equipment turned off, and the sound level due to rinse water spray noise (Yantek et al. 2005).

Results and discussion - determination of major contributors to in-plant screen noise

Prior to beginning the noise control development process, it is important to understand the noise-generating mechanisms of a source. The contributions of drive noise, screening noise, and water spray noise have to be determined within the operating constraints of the coal preparation plant. Because the non-test screens could not be turned off when the test screen was used to process coal, the barrier-absorber was installed around the test screen to block the background noise generated by the non-test screens. With the non-test screens operating and the test screen turned off, the barrier-absorber reduced the sound level around the test screen by 11 dB(A). In addition, the levels measured with the test screen running were 8 to 12 dB(A) higher than the levels with the test screen off. Therefore, the sound levels due to the test screen could be determined without distortion from the background noise due to the non-test screens.

The screen sound levels for normal operation, drive noise, screening noise, and water spray noise were determined by measuring the sound levels around the screen while turning on or off different screen functions. For example, drive noise was determined by operating the test screen in "vibration only" mode with the coal flow turned off. It is assumed that the presence of the thin layer of coal on the screen deck would have a minimal effect on drive noise. The sound level for full operation of the test screen was 92 dB(A) and the sound level for drive noise was 91 dB(A). The sound level was only reduced by 1 dB when screening noise was eliminated, so drive noise is the dominant source in this case. The sound level for water spray noise was measured to be 80 dB(A). Because water spray noise is more than 10 dB(A) less than drive noise, water spray noise is insignificant in terms of the sound level around a screen during normal operation. Screening noise was calculated to generate a sound level of 87 dB(A). If it were possible to eliminate screening noise, the operating sound level of a screen would still measure 91 dB(A) due to drive noise. Therefore, drive noise must be reduced to decrease the operating sound level of a horizontal vibrating screen, and it is critical to determine the screen components that are the dominant sources of drive noise.

LABORATORY BEAMFORMING MEASUREMENTS TO DETERMINE SOURCES OF DRIVE NOISE

Beamforming was used to identify dominant sources of drive noise on a new 2.44-meter-wide by 4.88-meter-long horizontal vibrating screen. Beamforming is a technique that identifies noise-generating components on a noise source by processing the sound pressures measured using a microphone phased array (Christensen and Hald 2004). The results of this analysis are used to generate a color-coded contour plot that shows dominant areas of noise radiation from the source overlaid on a picture of the source. Two sets of beamforming measurements were performed to examine noise sources on the screen. One set was performed with a 1.9-meter-diameter, 42-microphone array and the other was performed with a 3.5-meter-diameter, 121-microphone array.

The beamforming measurements were performed in the NIOSH OMSHR hemi-anechoic chamber with interior dimensions of 10.1 meters wide by 16.8 meters long by 6.4 meters high

(Peterson et al. 2012). A hemi-anechoic chamber is a special facility with a ceiling and walls that absorb nearly all incident sound and a floor that reflects nearly all incident sound. The sound field in the chamber mimics a free field over a large sound-reflecting plane (analogous to a large parking lot with no sound-reflecting objects other than the pavement).

The test screen used for these in-laboratory measurements was identical to the screens in the coal preparation plant where sound level measurements were taken. However, in the laboratory, the screen was supported by an A-frame (refer to Figure 4) whereas in the coal preparation plant the screens were connected to the building structure. For all tests, wooden wedges were driven under the A-frame rails to prevent the test screen from rocking on the floor.

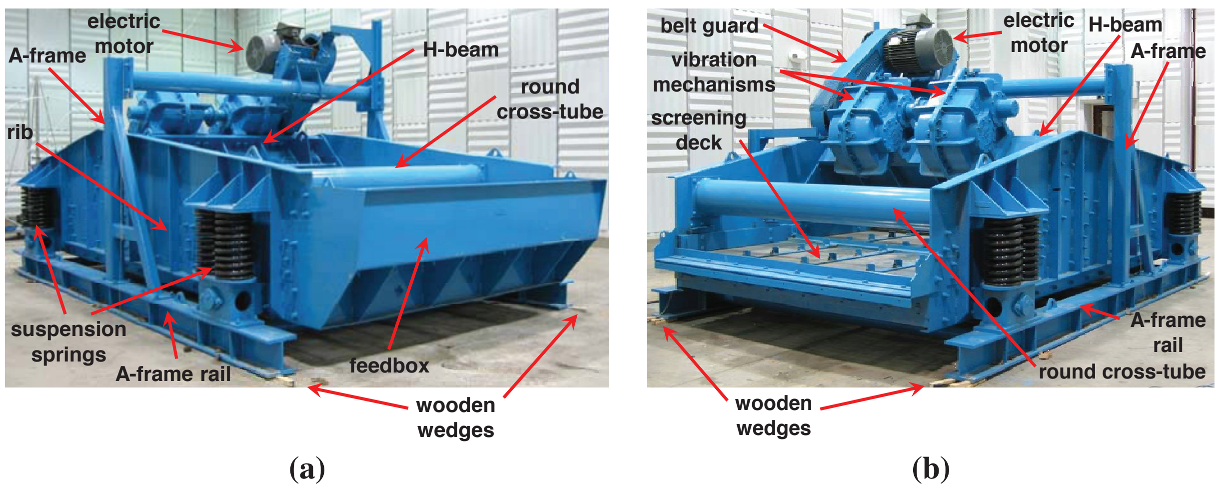


Figure 4.
Horizontal vibrating screen supported by an A-frame as viewed from the (a) feed end and (b) discharge end.

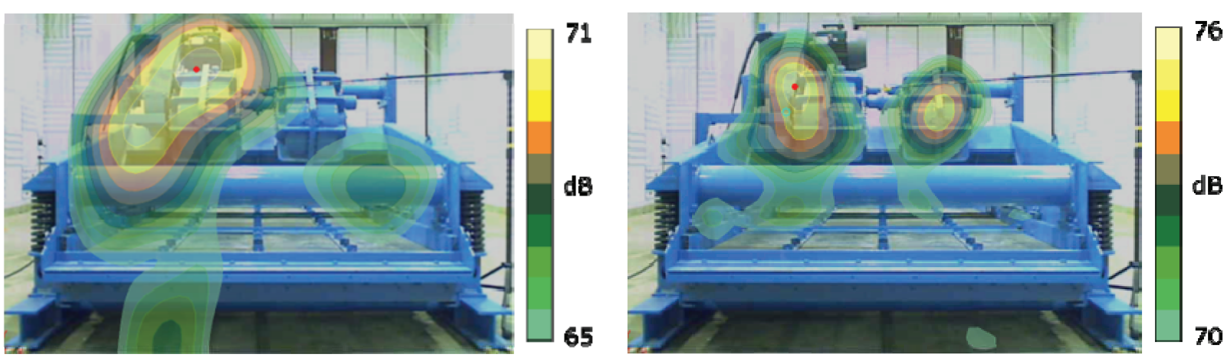
Test procedures – beamforming with 1.9-meter-diameter microphone array
The first set of beamforming measurements was performed using a 1.9-meter-diameter, 42-microphone spoked wheel array (Yantek et al. 2008). Measurements were performed with the array 5.54 meters from the sides of the screen and 3.05 meters from the ends of the screen (refer to Figure 5). The entire screen fit within the measurement area of the array for these positions. To examine noise sources with better spatial resolution, additional measurements were performed with the array 2.3 meters from the screen. Analyses with this array were limited to frequencies above 1 kHz because the spatial resolution for this array design is insufficient to examine noise sources below a frequency of 1 kHz.

(a) (b)

Figure 5.
(a) 42-microphone spoked wheel array and (b) array 5.54 m from the left side of the screen.

Results and discussion – beamforming with 1.9-meter-diameter microphone array

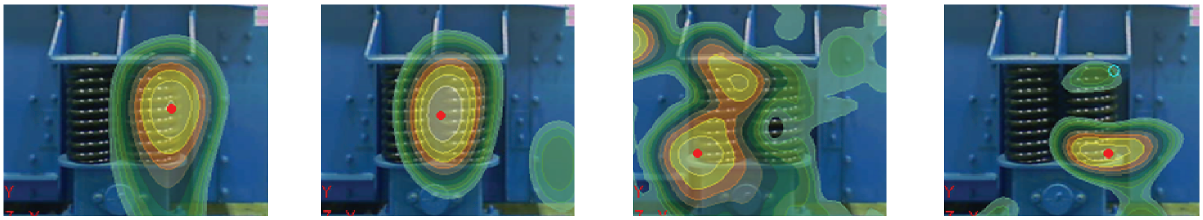
The beamforming results for the 1.9-meter-diameter array showed that above 1 kHz, the vibration mechanism housings are the dominant noise source (Yantek et al. 2008). In addition, the results indicated that the belt guard and steel suspension springs are significant noise sources. A close inspection of the belt guard revealed that one of the surfaces of the belt guard was intermittently rattling against the H-beam. Due to space limitations, only the results for the 1.25 and 2 kHz frequency bands are shown here (refer to Figure 6). The results for the 1.25 kHz one-third-octave band indicate that the right mechanism and belt guard are the dominant sources for this frequency band. The results for the 2 kHz one-third-octave band show that both mechanisms are significant noise sources, with the shape of the contours around the right mechanism suggesting that the belt guard is also a significant source.



(a) (b)

Figure 6.
Beamforming results for the feed end for the (a) 1.25 kHz and (b) 2 kHz 1/3-octave bands.

The data collected 2.3 meters from the screen side were processed to examine noise radiation from the springs on the left side of the screen. The results for the 1.28 kHz and 1.41 kHz frequency bands (refer to Figures 7a and 7b) show that the middle of the rear-most outer coil spring is an area of high noise radiation. The results for the 1.66 through 1.79 kHz and 2.08 through 2.14 kHz frequency bands (refer to Figures 7c and 7d) indicate that the ends of the springs are significant sources of noise. The last full spring coil could come into contact with the cut and ground coil at the ends of the springs, which would radiate noise.



(a) (b) (c) (d)

Figure 7.
Beamforming results for the left side, feed end coil springs for the (a) 1.28 kHz, (b) 1.41 kHz, (c) 1.66 through 1.79 kHz, and (d) 2.08 through 2.14 kHz frequency bands.

Test procedures – beamforming with 3.5-meter-diameter microphone array

To examine noise sources below 1 kHz, NIOSH OMSHR contracted Acoustical and Vibration Engineering Consultants (AVEC) to perform beamforming measurements using its 121-microphone, 3.5-meter-diameter star array (Camargo et al. 2009). The array was mounted to a movable truss to position the array for measurements from each screen surface (see Figure 8). The data were post-processed using AVEC's analysis software to generate contour maps for each array position using conventional beamforming with diagonal removal (Mueller 2002).

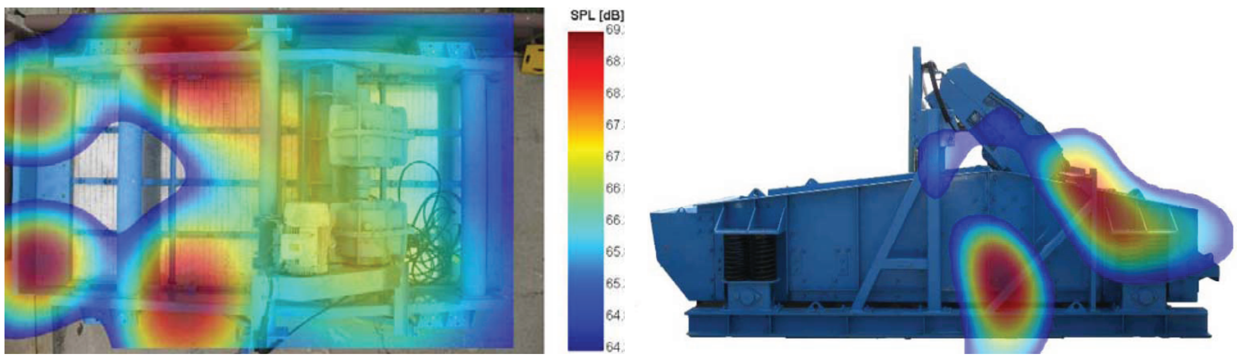
(a) (b)

Figure 8.
AVEC Array positioned (a) to the left side of the screen and (b) above the screen.

Results and discussion – beamforming with 3.5-meter-diameter microphone array

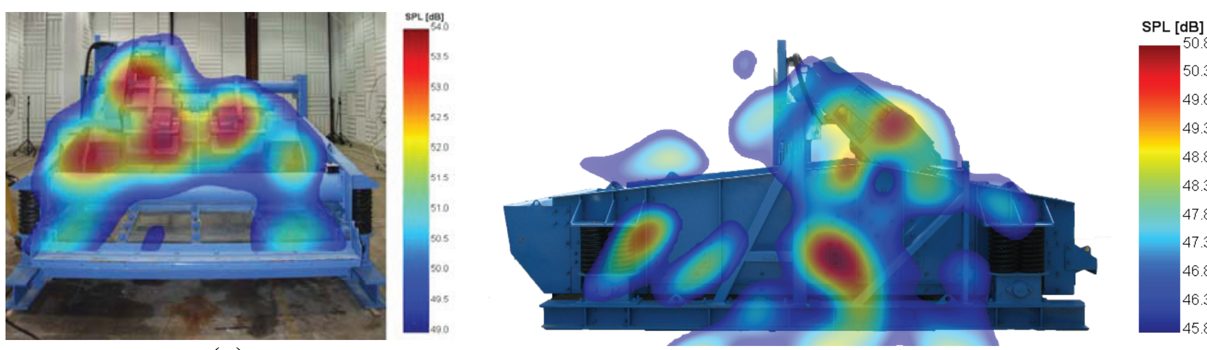
The testing with the 1.9-meter-diameter array revealed that belt guard rattling was a significant noise source. However, it is easy to eliminate belt guard rattling by increasing the clearance between the belt guard and the H-beam. The belt guard was removed prior to collecting data with the 3.5-meter-diameter array to make it easier to identify other sources.

For the 250 through 630 Hz one-third-octave bands, the screen body was shown to be the dominant noise source. The screen sides and feedbox were the main areas to radiate noise in these bands. Due to space limitations, only the results for the 315 and 500 Hz one-third-octave bands are shown here (refer to Figure 9). For the 800 Hz one-third-octave band, the screen sides and the mechanism housings were found to be significant noise sources (refer to Figure 10).



(a) **(b)**

Figure 9.
Beamforming results for the (a) 315 Hz and (b) 500 Hz 1/3-octave bands.



(a) **(b)**

Figure 10.
Beamforming results for the 800 Hz 1/3-octave band with array (a) at the feed end and (b) to the right side of the screen.

NOISE CONTROL EVALUATION USING SOUND POWER LEVEL MEASUREMENTS

The beamforming results indicated that the screen body, mechanism housings, and suspension springs are the most significant noise sources. The belt guard was also found to be a significant noise source. Noise due to belt guard rattling could be solved by increasing the clearance between the belt guard and the H-beam, so the belt guard was removed to eliminate noise from belt guard rattling. This allowed more attention to be devoted to the other noise sources that are not so easily addressed. Noise controls were applied to reduce noise from the steel coil springs, mechanism housings, and screen body, and their effect on the sound power level of the screen was measured.

Noise control description – rubber spacers for coil springs

After the beamforming images were examined, a test was conducted to determine what caused the coil springs to radiate noise. A stroboscope was used to observe the motion within the coil springs while the screen was running. Contact was observed to occur between the last full coil and the cut and ground coil on the outer coil springs (refer to Figure 11). A strip of a 6-mm-thick, 60 durometer rubber was installed between the last full coil and the cut and ground coil of all coil springs to prevent coil spring chatter.

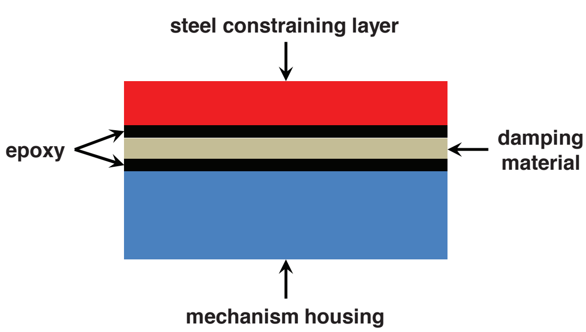
(a)

(b)

Figure 11.
(a) Contact location between spring coils and (b) rubber spacer used to prevent spring chatter.

Noise control description – mechanism housing constrained layer damping

Constrained layer damping (CLD) is a technique used to convert mechanical vibration energy into a small quantity of heat. CLD was applied to the mechanism housings to reduce their contribution to noise as shown in Figure 12 (Lowe et al. 2010). First, the paint was removed from the flat areas of the mechanism housings where the damping treatments would be applied and these areas were cleaned of all oils and contaminants. Next, an 80 durometer, 0.6-mm-thick viscoelastic damping material was bonded to the mechanism housings using epoxy. Finally, 6-mm-thick steel plates were bonded to the damping material to serve as the constraining layer.



(a)

(b)

Figure 12.
(a) CLD treatment and (b) locations for CLD treatments on vibration mechanism housings.

Noise control description – mechanism enclosure

A vibration mechanism enclosure was developed to reduce the noise radiated by the vibration mechanisms (Lowe et al. 2010). A modular panel-on-frame design was used to provide a relatively stiff structure for the individual enclosure panels (refer to Figure 13). The frame was built using 5-mm-thick, 50-mm-wide angle stock and 6-mm-thick, 50-mm-wide by 16-mm-deep U-channel. Dynalam damped steel was used to fabricate the panels. The enclosure was lined with 25-mm-thick acoustic foam to reduce the buildup of reverberant sound within the enclosure. The panels were bolted onto the frame using anaerobic thread locker to help prevent vibration-loosening of the fasteners.

(a) (b)

Figure 13.
(a) Frame for mechanism enclosure and (b) assembled mechanism enclosure.

Noise control description – mechanism suspension

Vibration isolation is a method used to prevent the transmission of mechanical energy between machinery components. A mechanism suspension was designed to allow forces to be transmitted from the mechanisms to the screen body at the mechanism operating frequency while isolating higher frequency energy due to bearing forces, gear meshing forces, etc. An H-beam cap was welded to the existing H-beam to facilitate the use of vibration isolators to support a raft to which the vibration mechanisms are attached (see Figure 14a). Twenty-four two-piece vibration isolators made from natural rubber were installed in the H-beam cap (see Figure 14b). The vibration isolators use a protective steel sleeve to prevent the support structure from cutting into the rubber. The vibration mechanisms were disconnected from the H-beam and mounted to a steel raft which was then bolted to the H-beam cap through the two-piece vibration isolators (see Figures 14c and 14d). The spring rates for the vibration isolators were selected so that forces would be transmitted to the screen body at the mechanism operating speed, 900 RPM, while higher frequency forces would be attenuated. In addition, the relatively high stiffness suspension prevented transient problems with pitching motions during start-up and shut-down of the vibration mechanisms (Yantek and Lowe 2011).

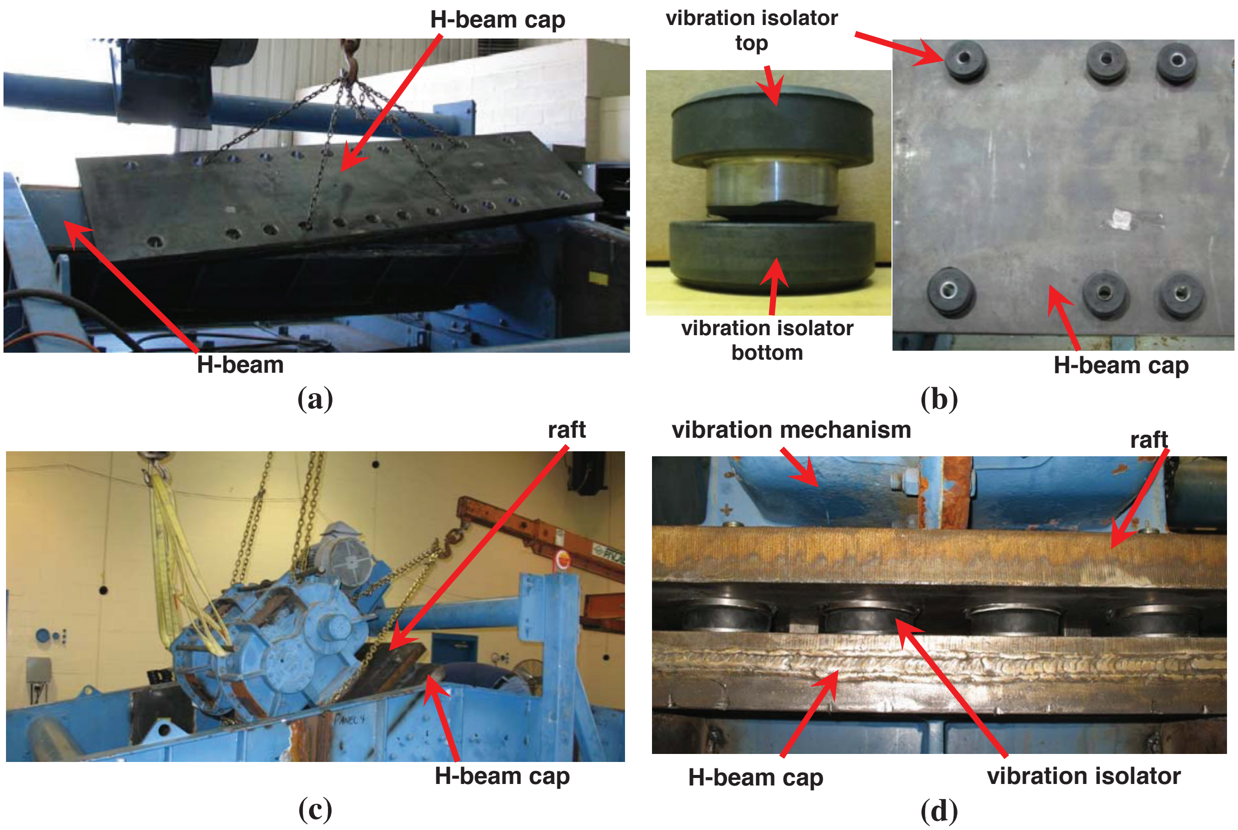


Figure 14.
Mechanism suspension – (a) H-beam cap installation; (b) vibration isolators installed in H-beam cap; (c) mechanisms and raft installation; and (d) close-up of installed suspension.

Test procedures – sound power level measurements
The sound power level of a noise source is a measure of the acoustic energy radiated by that noise source and it is independent of the acoustic environment. In order to evaluate the effects of the noise controls, the A-weighted sound power level of the vibrating screen was measured in the NIOSH OMSHR reverberation chamber (see Figure 15), which is NVLAP-accredited for sound power level measurements. The comparison method was used to determine the sound power level of the screen in one-third-octave bands (ISO 1994). The comparison method uses a reference sound source that generates a known sound power level in one-third-octave bands to determine the sound power level of a sound source, in this case the screen.

Figure 15.
Sound power level measurements in the NIOSH OMSHR reverberation chamber: (a) reference sound source and (b) horizontal vibrating screen.

A Bruel & Kjaer Pulse data acquisition system and 15 Bruel & Kjaer Type 4188 microphones were used to acquire the data. A measurement time of 30 seconds was used for all tests. Wooden wedges were used beneath the screen rails to prevent the screen from rocking on the chamber floor. The operating speed of the screen's eccentric mechanisms was checked periodically throughout the tests with a tachometer. The sound power level was measured for the following configurations: (1) baseline (with belt guard removed); (2) CLD on mechanism housings and elastomeric spring inserts; (3) CLD on mechanism housings, elastomeric spring inserts, and mechanism suspension; and (4) CLD on mechanism housings, elastomeric spring inserts, mechanism suspension, and mechanism enclosure.

Results and discussion sound power level measurements

The sound power level measurements were carried out for the previously mentioned configurations. Figure 16 shows the A-weighed, one-third-octave-band sound power levels and the overall A-weighted sound power level for each configuration. The sound power level for the baseline configuration was 100.5 dB(A). The spectrum for the baseline case exhibits two humps. One hump extends from 100 Hz to 1 kHz and the other from 1k Hz to 10 kHz. Recall that below 1 kHz, the screen sides and feedbox were shown to be the most significant sources of noise; above 1 kHz, the mechanism housings were shown to be the most significant noise sources and the coil springs were also observed to be sources of noise.

Several controls were developed and applied to address the identified noise sources. After the CLD treatments were applied to the mechanism housings and the rubber spring inserts were installed, the sound power level was reduced to 97.8 dB(A). The most significant reductions for this configuration occurred at frequencies above 1 kHz. Next, the mechanism suspension was added to the CLD treatments and spring inserts. The sound power level was reduced to 96.4 dB(A)—a modest reduction. The mechanism suspension made significant reductions in the 200, 250, and 315 Hz one-third-octave bands, but the sound power levels in the 2500 and 3150 Hz one-third-octave bands increased. The increases could be due to the addition of the steel raft, which increases the vibrating surface area that can radiate noise. Finally, installing the enclosure reduced the sound power level to 94.9 dB(A)—a 5.6 dB(A) reduction compared to the baseline. In addition to reducing mechanism housing radiated noise, the enclosure also covers most of the raft. It could, therefore, reduce raft-radiated noise.

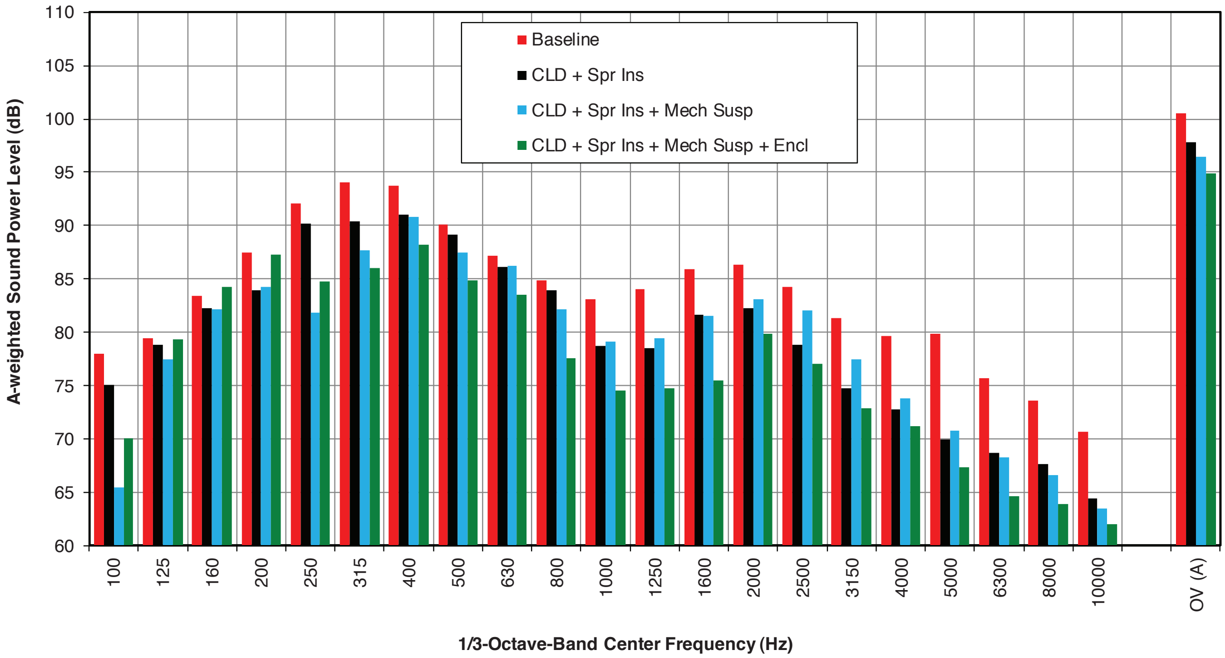


Figure 16.
A-weighted sound power level in one-third-octave bands for several screen configurations.

CONCLUSIONS

The major contributors to the noise radiated by a single horizontal vibrating screen were determined in an operating coal preparation plant. Drive noise was found to be the most significant contributor to the sound levels radiated by a horizontal vibrating screen used to process clean coal. Screening noise was determined to be a secondary contributor. In-laboratory beamforming measurements identified the screen body, mechanism housings, and suspension springs as the most significant noise sources. Installing constrained layer damping (CLD) treatments on the mechanism housings, rubber inserts in the steel suspension springs, a mechanism suspension between the vibration mechanisms and the H-beam, and a mechanism enclosure reduced the sound power level of a screen by 5.6 dB(A).

Of the tested noise controls, the spring inserts and the CLD treatments are the easiest to retrofit onto existing screens. However, these noise controls only address part of the noise radiated by screens. When added to the spring inserts and the CLD treatments, the mechanism enclosure and mechanism suspension complete a noise control package that reduces screen noise by nearly 6 dB(A)—a 75% reduction in the A-weighted sound energy.

It should be emphasized that installing a mechanism enclosure or a mechanism suspension are not trivial tasks. In addition, using a mechanism enclosure may create problems with heat buildup inside the enclosure that could decrease bearing life. Furthermore, an enclosure may not be acceptable to workers because of the perception that it will interfere with ordinary maintenance tasks. Due to space limitations, it would be difficult to install a mechanism suspension within a working coal preparation plant.

To implement an enclosure that is practical for field use, a screen manufacturer must reengineer the design of its vibration mechanisms. The mechanism housing design could be modified such that an outer shell is "floated" from an inner shell to realize a close-fitting enclosure that will reduce mechanism housing radiated noise without forcing a mine to retrofit a bulky enclosure. A new mechanism suspension would need to be designed to isolate high frequency energy from the screen in a less cumbersome manner. A vibrating screen manufacturer could apply vibration isolation at the interface between the eccentric mechanism shafts and the eccentric mechanism housings. With a mechanism suspension that incorporates the proper combination of stiffness and damping between these components, the high frequency forces transmitted to both the screen body and the mechanism housings could be significantly decreased. Successfully modifying the vibration mechanism design could result in screens that generate significantly less noise without sacrificing bearing life, maintenance, or practicality.

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