Measurement method for determining absorption coefficients for underground mines

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Introduction

Underground miners are exposed to more noise than aboveground miners. This is because mine ribs and roof reflect sound that would normally be lost to the atmosphere in an aboveground operation. The amount of sound reflected is a function of the mine's geometry and the type of material being mined. The acoustic environment that mining machines operate in is a critical factor affecting sound pressure levels. Underground mines consist of enclosed areas that create diffuse sound environments. The geometry and composition of the surfaces determine the number of sound rays reflected or absorbed, which influences the overall sound level. This property is known as the Sabine absorption coefficient (α), which is used to describe the degree of reflectivity of the walls, floor and roof. However, not all of the sound is reflected, some is absorbed by the surfaces of the walls, floor and roof. Determining the sound absorption coefficient is essential in describing the sound field in an underground mining environment.

Classic absorption estimations are usually made using an impedance tube or by conducting T60 measurements. Impedance tube testing is an inappropriate method for determining underground absorption coefficients due to the brittle composition of materials such as coal and slate. Classic absorption coefficient estimation using T60 measurements do not work well in an underground environment because the theory assumes a finite room, a diffuse field and a relatively uniform absorption. None of these assumptions are true in an open-ended mine entry. Therefore, a new method for determining absorption coefficients is needed for underground mines.

Concept for determining the absorption coefficient

The concept assumes that the mine entry is an "infinite" duct, i.e., very little of the acoustic power traveling down the duct is ever reflected back into the source area. To determine the absorption coefficient, the measurements are matched to a ray-tracing-based model (or image-source model) of the acoustic field radiated from the source in an "infinite" duct.

This modeling approach utilizes a ray-tracing-based technique that can be used to predict sound fields in mines of various shapes and sizes. A computer program models the noise source as a point or series of points emitting rays of sound energy in a random or deterministic fashion. Each ray is reflected and scattered by surfaces, barriers and objects as it travels until it reaches a receiver. A contour map generated from an array of receiving

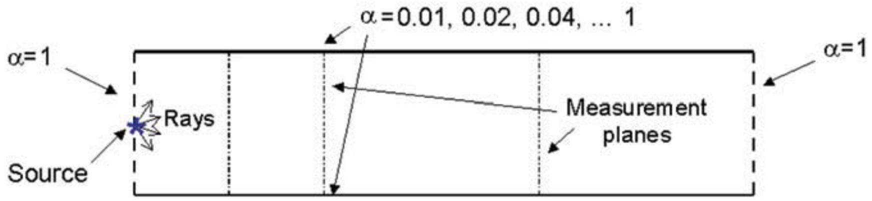
Abstract

Previous studies conducted by the National Institute for Occupational Safety and Health (NIOSH) have shown that approximately 90 percent of coal miners and 49 percent of metal/nonmetal miners had a hearing impairment by age 50 (Franks, 1997). Mine workers are exposed to additional noise levels underground due to the reflection of machine-generated noise that would otherwise dissipate in an aboveground setting. Determining the sound-absorption coefficients is essential in modeling the sound field in an underground mining environment. Sound absorption is a measure of the amount of acoustic energy that strikes a surface and is absorbed rather than being reflected. The acoustic environment that mining machines operate in is a critical factor affecting the sound pressure level exposure for mining machine operators. Impedance tube testing is an inappropriate method for determining underground absorption coefficients due to the brittle composition of materials such as coal and slate. Classic absorption coefficient estimation using T60 measurements will not work well in an underground environment because the theory assumes a finite room, a diffuse field and a relatively uniform absorption. None of these assumptions are true in an open-ended mine entry. This paper presents a method using a ray-tracing technique to determine absorption coefficients for underground mines. Absorption coefficients are determined and presented for octave bands from 63 Hz to 8 kHz. The absorption coefficients are essential for determining and predicting potential overexposure to machine operators in different mine environments.[1]

[1] *The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.*

FIGURE 1

Modeling plan using ray-tracing techniques.



points predicts the sound field.

The mine entry is modeled as a finite-length entry with 100 percent absorption ($\alpha = 1.0$) at both ends to make it appear infinite (see Fig. 1). This model is used to calculate the sound-pressure level (SPL) at the measurement positions with varying absorption coefficients at the roof and ribs of an underground mine.

Because the entry is fairly wide, approximately 4.5 m (15 ft) across, this method should work well, even at low frequencies.

Underground measurement procedure

The calibrated noise source (fan) is positioned near the end of a crosscut or the edge of the mine entry, as shown in Fig. 2. Figure 3 shows a picture of the calibrated noise source used for conducting the underground mine tests.

The noise source (fan) is placed at the center of the crosscut with equal distance horizontally and vertically between the roof, floor and ribs. The exact position of the noise source is recorded and documented for analysis procedures to determine the absorption coefficients. The octave-band sound power levels for the calibrated noise source are shown in Table 1.

Additionally, the dimensions of the crosscut are measured and recorded. The crosscut is divided into equal areas or subsections and the center of each subsection represents a measurement location, as shown in Fig. 2. Several cross-sectional measurement planes are marked in the entry at increasing distances from the noise source and divided into six subsections. Within each subsection, the sound pressure level generated by the calibrated noise source is measured and recorded. A Brüel and Kjaer 2260 Investigator (Fig. 4) is used to collect the octave band data. The Brüel and Kjaer 2260 Investigator is a handheld real-time octave and one-third octave band device with frequency analysis, statistics and logging capabilities.

Utilizing the measurement scheme from Fig. 2 for underground testing, the calibrated noise source (fan) is placed just inside the left open end of the crosscut. A total of 48 octave-band measurements are performed using the Brüel and Kjaer 2260 Investigator for characterization of the acoustical mining environment. Two measurements are conducted at each of the 24 monitoring points within the crosscut. At each monitoring point, a measurement (bottom point) is located 0.7 m (2.3 ft) from the floor and the second measurement is performed 1.4 m (4.6 ft) (top point) from the floor. Figure 5 shows the measurement locations (1 through 24) and the position of the measurement planes with respect to the noise source.

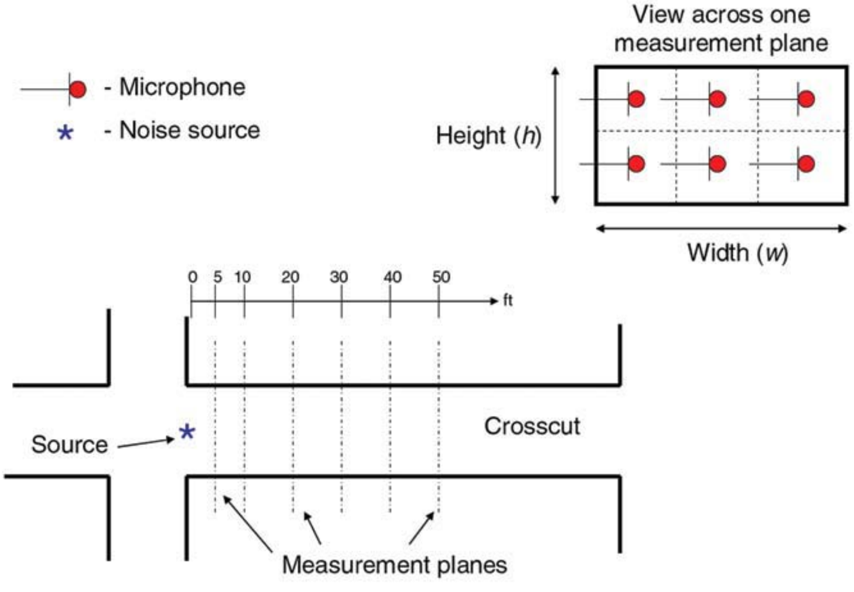
Raynoise program

Raynoise is the core noise modeling software (LMS International, 2003). It uses a ray-tracing-based technique to calculate the noise characteristics of a given source/room configuration. A key aspect of the package is that the noise sources and material properties are defined in terms of a full octave rather than a one-third-octave format. It has the capability of importing model information into the AutoCAD DXF format. This package also has command file capabilities that allow complete model and test definitions to be written and processed. This is convenient for processing a variety of tests in bulk and for varying parameters for a single test. It also has command-line operation capabilities that allow it to be used as a "black box" by other software.

A limitation of this package is that it can only make calculations for a specific frequency. To generate overall results, a model must be run at each octave band frequency and the resultant SPLs for each band are then combined outside of the Raynoise software. Another limitation is the breakdown of the model in the near field. When measurement points are placed too close to the noise source, the calculations grow increasingly inaccurate. Experience, suggests measuring points be separated by at least 0.5 m (1.6 ft), preferably a full meter.

FIGURE 2

Measurement scheme used in determining the absorption coefficients in an underground mine environment.



Procedure for determining absorption coefficient

The field data are downloaded to

the PC in Excel format, one file for each measurement point. These files are processed by a custom utility program to merge their results into one file (text format, comma delimited). If the data are in one-third octave format it is converted to full octave format with the overall value based on the logarithmic sum of the one-third octave values.

The test conditions documented from the underground testing in Fig. 5 are used to create an equivalent underground model utilizing the Raynoise package. The specific information used for input into the Raynoise package consists of:

- the X, Y and Z coordinates of the calibrated noise source;
- the height above the floor of the bottom and top measurement points, as shown in Fig. 2;
- the total length of the crosscut being examined;
- the crosscut height and width at each measurement plane location; and
- the sound power output of the calibrated noise source in full-octave band format, as displayed in Table 1.

FIGURE 3

Calibrated noise source for underground testing.

FIGURE 4

Brüel and Kjaer 2260 Investigator.

Using the test information described above, an equivalent Raynoise model is constructed. The geometric information for the equivalent model is created through the development of an AutoCAD drawing of the crosscut and imported into the Raynoise package. The measurement points within the model are then defined using the underground measurement data to define the top and bottom measurement points for input into the Raynoise model. The calibrated noise source is then placed in the position as performed for the underground measurements and the sound power output is set. The equivalent Raynoise model is shown in Fig. 6.

A full octave band test of the model is then processed using the Raynoise program. The calculated linear sound pressure level (SPL) results are output to a file (text-based, comma delimited) for comparison to the measured data. Both files (overall measured and calculated) are then imported into Excel. Charts are generated plotting measured vs. calculated SPL at each measurement point for each octave band SPL and the overall SPL.

Comparing the results at each octave band, the modeled absorption coefficients are adjusted to bring the calculated SPL results closer to the measured and the model is processed again. These steps are repeated until the average of the error between measured and calculated has been minimized. The result is a set of octave band absorption coefficients for the mine entry.

Results

The predicted sound pressure levels were most accurate at the middle to higher frequency levels, 500 Hz through 4 KHz. Table 2 lists the average errors across the measurement points for all of the octave bands. For the 1 through 8 KHz frequencies, these errors were essentially uniform across all of the measurement points. Predicted values closely tracked the measured values with correlation coefficients of 0.96 or better.

Table 1

Octave-band sound power levels for calibrated noise.

Octave band, Hz	Sound power, dB
63	79.8
125	83.9
250	84.7
500	84.9
1,000	87.5
2,000	87.7
4,000	85.7
8,000	83.6

Table 2

Average error between measured and calculated values for each octave band.

Octave band, Hz	Average error between measured and calculated, dB
63	2.0
125	1.8
250	2.1
500	1.1
1,000	0.6
2,000	0.7
4,000	1.0
8,000	1.6

FIGURE 5

Measurement locations for determining acoustical properties underground.

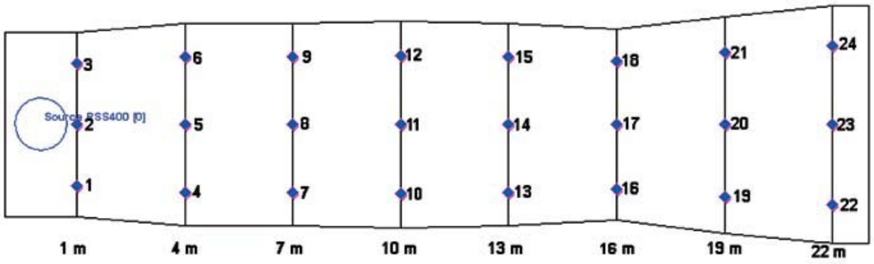
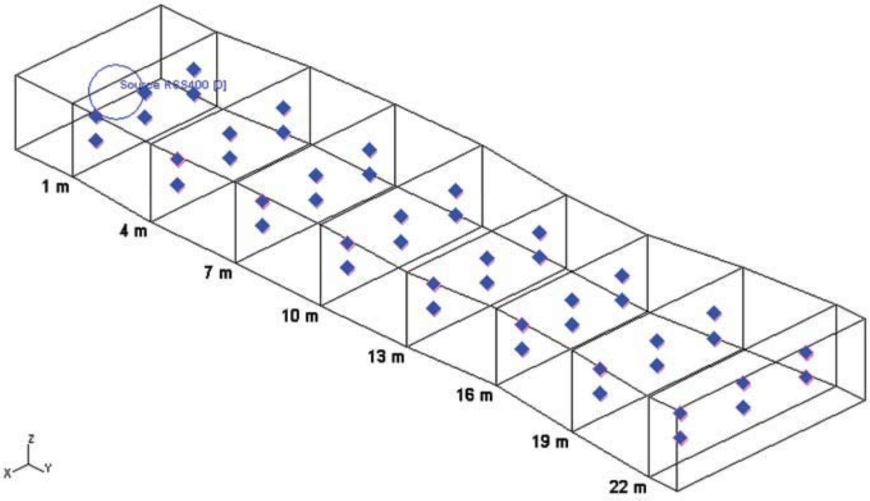


FIGURE 6

Equivalent Raynoise model of field test. The diamonds represent planar measurement points.



At the lower frequencies, 63 through 500 Hz, error levels increased with distance from the noise source. The correlation between measured and predicted values begins to decrease dramatically from the 250 Hz band (correlation coefficient of 0.87) down to the 63 Hz band (correlation coefficient of 0.42). The poor performance at these frequencies may be due to the noise source output decaying into the background noise levels. This would indicate a need for a calibrated noise source with stronger output levels at these frequencies. The poor performance could also be due to additional noise from other sources not accounted for at the far end of the mine entry. In other words, the background noise may not be uniform along the entire entry.

Once the data is filtered using an A-weighting algorithm, the larger error differences in the lower frequency bands become negligible due to this type of filtering. Therefore, the differences in measured and calculated sound pressure levels of the model provide a good fit, and the final absorption coefficients determined from the model are shown in Table 3.

It should be noted that, due to the background noise levels being so close to the noise source output levels at the frequencies of 63, 125 and 250 Hz frequencies, the confidence in the absorption coefficients for these frequencies is not very high, especially at the 250 Hz frequency. While the value noted above provides the best fit to the available data, it does not seem to follow the general trend.

Conclusions

Determining the sound absorption coefficients is essential in describing the sound field in an underground mining environment through computer-based modeling. Once the absorption coefficients are known, the sound level exposure for the operator can be predicted based on the acoustic characteristics of the environment. This technique provides a viable method for determining the octave band sound absorption coefficients in underground mines. The absorption coefficients will be essential for predicting possible overexposure of machine operators in different mine environments via computer-based modeling.

The poor performance at the lower frequencies could be improved by accounting for the background noise levels from other sources at the far end of the mine entry. In addition, using a calibrated noise source more powerful in the lower frequencies could also help alleviate background noise interference.

However, once the data is filtered using an A-weighting algorithm, these differences are diminished. Therefore, the differences in measured and calculated sound pressure levels of the model provide a good fit, and this provides a viable method for determining the octave-band sound absorption coefficients, not only in underground coal mines but in all underground mines.

References

Franks, J.R., 1997, "Analysis of audiograms for a large cohort of noise-exposed miners," Internal Report, National Institute for Occupational Safety and Health, Cincinnati, OH, pp. 1-7.

LMS International, 2003, Raynoise Revision 3.0, Building Acoustics and Industrial Noise Simulation, User Manual.

Table 3

Final absorption coefficients determined from model runs.

Octave-band, Hz	Absorption coefficient
63	0.03
125	0.04
250	0.20
500	0.14
1,000	0.15
2,000	0.19
4,000	0.28
8,000	0.45