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# Engineering Controls for Noise Abatement

By John Erdreich, PhD

Acoustical engineers are often involved with two types of noise control engineering problems. In the most common, an existing condition of excess employee noise exposure has been identified, compensation claims have been filed against an employer and/or employee complaints have been raised. Less common, when planning a new facility, the engineer is asked to design equipment layout and to select equipment to minimize employee exposure. In either case, a model is used that is referred to as *source/path/receiver*. This model segregates the noise control problem into three distinct parts. The first, the *source*, relates to noise emitted by equipment and modifications that are feasible for the equipment itself. The second, the *path*, deals with the transmission of sound from the source to the affected employee. At this point, the engineer evaluates methods such as barriers or enclosures which limit transmission of sound. Finally, the *receiver* component of the problem addresses the employee and feasible methods of mitigating employee exposure. Frequently, these consist of administrative controls or the use of hearing protection devices (HPDs).

> The design of engineering controls for noise abatement follows a formal process in which the first phase, selection of the exposure criterion, and the second, measurement of employee exposure, dictate the complexity of the engineering controls required for implementation. This article reviews the *source/path/receiver model* for reducing noise exposure.

The first consideration in evaluating a noise control project is to determine the employee's exposure and the criterion acceptable exposure level. Sound level is normally measured in terms of the average A-weighted sound level. The differences between A-weighted sound and other sound metrics, such as C-weighted sound level and octave band sound level, are described in the sidebar on page 46. Exposure is measured in terms of dose which takes into account time and sound level. By convention in the U.S., 100% dose is equivalent to 90 dBA for eight hours. For every 5 dB increase of level, duration must be cut in half to maintain equivalent dose.

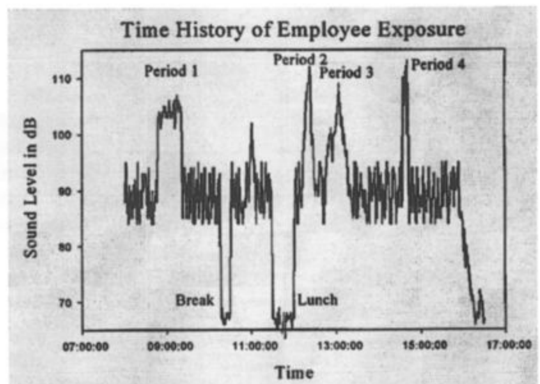


**Fig. 1.** *A typical time course of exposure for a maintenance worker.*

An important issue is the manner in which the employee dose is determined. Typically, employee exposure is measured with either a sound level meter or with a dosimeter. Using a sound level meter requires some strategy for sampling the exposure of an individual, both in time and in terms of job assignment. This technique is most useful where the exposure of the worker is constant or is predictable. In other situations, dosimeters provide an easier, potentially more accurate exposure assessment.

There are two types of dosimeters currently in use. One provides a single value for the dose mea-

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sured over the sampling period while the other, a time-history dosimeter, provides a minute-by-minute record of the sound exposure. The advantage of the time-history dosimeter is that it allows the noise control engineer to determine how the sound exposure develops and, with appropriate observation, the sources that cause the primary exposures.

Since the determination of the source of an employee's exposure is critical to the success of the noise control project, it is worthwhile to examine the type of information that is provided by a time-history dosimeter. As shown in Fig. 1, exposure typical of a maintenance worker assigned to different areas and different processes during the work shift produces an overall exposure comprising several periods of high levels of noise and a majority of moderate noise levels. High-level noise exposures are labeled Periods 1-4. In a facility such as an automotive garage, these periods could correspond to the use of pneumatic tools or chipping hammers. In this example, the employee's exposure corresponds to 204% dose over the work shift. Of this exposure, 139% corresponds to the four periods labeled in Fig. 1. The remaining exposure, 65%, is accumulated during the remainder of the shift. If the sources which contribute to the exposure during the four labeled periods can be identified and mitigated, then the exposure of this employee can be brought within compliance limits prescribed by OSHA.

Calculations based on the time history data reveal that Period 1 contributes a dose of 55%. Period 2 contributes 32%, Period 3 contributes 28% and Period 4 contributes 24% dose. By examining the worker's job requisitions, by asking the employee to keep a task log during the survey, or by observation, each interval can be correlated with a particular task on which information the engineer can determine where to concentrate noise control efforts. For example, if Period 1 represents the noise exposure created by removing a muffler with a pneumatic chisel, then substitution of a different tool or technique may substantially reduce the employees' exposure.

## Criterion Selection

Generally, selection of the appropriate employee exposure criterion is straightforward. OSHA regulations mandate that employee exposure be limited to the equivalent of 90 dB TWA (100% dose) in the absence of personal protection. The OSHA regulations also mandate that exposures be limited to 85 dB TWA (50% dose) in the absence of a hearing conservation program. Therefore, the employer faces a relatively straightforward decision:

1) Exceed 90 dB then offer HPDs, monitor their proper use and implement a hearing conservation program;

2) Exceed 85 dB and implement a hearing conservation program; or

3) Reduce exposures below 85 dB and require neither HPDs nor a hearing conservation program.

These decisions are administrative and economic choices made by the employer; they are not engineering decisions. However, a noise control survey carried out by an experienced acoustical engineer can put the decisions in perspective.

## Remediation Projects

For projects involving remediation or mitigation of existing noise exposure, the steps to be followed are:

- Exposure measurement.
- Determination of exposure sources.
- Comparison with criterion exposure.
- Implementation of noise control.

## Exposure Measurement

Whichever equipment is selected for exposure measurement, there are procedures that must be followed to assure that appropriate data are taken in a manner which provides comparison with other exposure measurements and that the measurements are comparable across instruments. Calibration of equipment is essential in these measurements. American National Standard "Measurement of Occupational Noise Exposure" (ANSI S-12.19-1996) describes the procedures to be used in measurement of employee exposures. The standard covers instrument calibration, documentation, microphone placement, as well as containing definitions of terms which are important in measurement of occupational exposure. It is an excellent reference which covers much more material than can be included in this brief article. Several additional sources of information on the topic are included at the end of this article as *Suggested Readings*.

## Determining Exposure Source

With exposure data in hand, it is now possible to determine the sources which contribute to the total exposure. In the case of data taken with a sound level meter, the engineer may investigate the sound sources in proximity to the worker position to identify contributing sources. For data taken with a time-history dosimeter, these sources may be identified by correlating worker position or task with the sound level as shown in the example above. After identifying the source, it is important to determine the sound level contributed by that source. Several techniques are available to do this, such as measurement and comparison of the sound spectrum in the vicinity of the worker with the machines located nearby, measuring sound levels with sources turned off and on, and "walk-away" measurements in which the sound level changes with distance. Techniques such as these are described in textbooks on noise control engineering.

## Comparison with Criterion

After determining the contributions of noise sources to the exposures, there is sufficient information to calculate the degree of noise mitigation needed. This is the difference between the criterion selected by management and the measured noise exposure.

## Types of Controls

The types of controls available for noise abatement are as numerous as the sources of sound itself. Typical noise source categories and examples of the category are shown in Table 1. High frequency noise is generally easier to mitigate while low frequency noise is generally less intrusive. Procedures which can reduce the amount of energy a process produces or which can dissipate that energy over a longer time will reduce the noise produced.

As examples, reducing rotation speed of a machine will reduce the frequency of the sound it produces. Reducing the number of fan blades or gear teeth will have the same effect. Cutting material gradually with a progressive knife rather than shearing it all at once will reduce the impact sound created.

Perforating the metal used as a guard over a rotating sheave renders it less able to radiate sound, which has the effect of reducing the noise produced by vibration of the guard. Another method of reducing radiated sound is to limit the amplitude of vibration itself. This is accomplished by adding a damping layer to a radiating surface in which the vibration energy is dissipated. Examples of damping materials are soft substances, such as rubber compounds, that can be applied to the surface.

Probably the most common source of noise in plants we have visited is the compressed air blow-off. These are usually tubes or valves with no special treatment of the nozzle. Turbulence produced by these devices creates intense noise. Treatment of the blow-off to produce smooth laminar flow at the orifice substantially limits turbulence and, therefore, noise generation. Another common cause of excess noise exposure is poorly maintained equipment. Incorrectly tensioned drive belts, for example, can cause extreme high pitch noise.

## Path Controls

Path controls are generally similar for all types of noise sounds. These types of controls are shown in Table 2. Noise barriers work by creating an "acoustical shadow" between the sound source and the receiver much as a wall creates a shadow between a flashlight and an observer. Their effectiveness is limited by reflections of the source by the ceiling of a room, by the distance between the barrier height. If used indoors, it is important to control reflections from the ceiling by the use of appropriate absorptive ceiling materials.

Enclosures, depending on materials and construction, may provide effective reduction of sound transmitted from source to receiver. The amount of sound reduction can be increased by adding mass to the walls, by adding absorption to the inside surfaces of the enclosure and by adding a second enclosure separated by an airspace. However, in many cases, heat must be rejected from the enclosed equipment which will require an acoustically treated ventilation path. For single wall enclosures, the practical limit of attenuation is about 45 dBA.

Mufflers are available in a wide variety of types and sizes. They may be applied to the inlet and the exhaust of equipment or they may be inserted in a duet which is part of a ventilation path for equipment. Generally, two types of mufflers are common: *absorptive* mufflers, in which sound is absorbed in material along the interior sides of the muffler and *reactive* mufflers, which are tuned to reduce the transmitted sound.

A muffler cannot be added to a system with impunity. All of these devices add some pressure drop to the system to which they are added. The system must be capable of overcoming this pressure drop if adequate air movement is to be maintained. Furthermore, the incremental operating cost caused by this pressure drop may be an important consideration, especially where high pressure drops are caused by the device.

**Table 1. Examples of Sound Sources and Engineering Controls**

| Source Type | Example | Generic Source Control |
|---|---|---|
| Rotating Machinery | Gears<br>Fans | Reduce rotation speed<br>Change number of blades/teeth |
| Impacts | Shears<br>Punches | Use progressive cut<br>Use staged die |
| Surface Vibration | Shields/Guards<br>Bins/Conveyors | Perforate large surfaces or add damping layer |
| Air Turbulence | Blow-off<br>Rotating Knives | Use laminar flow nozzle<br>Reduce air volume resonance |

**Table 2. Path Noise Controls**

| Source | Type | Approximate Maximum Reduction |
|---|---|---|
| Outdoor source<br>Indoor source with sound absorptive ceiling | Barrier | 15 dB |
| Indoor/Outdoor sources<br>May need supplemental ventilation | Enclosure | 45 dB+ |
| Ducted fan or engine exhaust | Muffler | 5 dB low frequency<br>45 dB high frequency |
| Any source in a room with reflective walls | Absorption | 3-6 dB |

Frequently, we see cases of attempted noise control in which a client has added suspended or wall-mounted acoustical absorption panels. Sound levels at any location in a room are the sum of sound radiated directly from the source to the observer and reverberant sound reflected from room surfaces. In cases where the reverberant sound level in a room dominates at a location, acoustic absorption can be helpful.

For every doubling of absorption in a room, the reverberant sound level will decrease by 3 dB. Direct sound level will be unaffected. In a space with little absorption, such as a gymnasium, adding absorption can be effective. However, in a typical factory or office where there is already a substantial amount of absorption, adding *additional* absorption quickly becomes ineffective. In fact, it may not be possible to add sufficient additional sound absorption to reduce the reverberant sound level by the first 3 dB. Existing acoustical absorption can be measured to determine how much additional absorption is needed to reach a criterion sound level and to determine if it is practical to do so.

## Receiver Controls

Most commonly, receiver controls use administrative techniques to reduce exposure time. These may involve rotating job assignments between noise and quiet tasks or subcontracting certain noisy tasks. Receiver controls also may consist of using HPDs (although these are really path controls). This topic is covered separately in other articles within this special edition of *The Hearing Review*.

## Planning vs. Remediation

New facility designs can benefit from modeling of the site to determine worker exposure before they occur. Several American National Standards specify how data should be acquired for input to this modeling. ANSI SS12.16-1992, "Specification of the Noise of New Machinery" provides guidelines for obtaining noise level data from manufacturers of stationary equipment. ANSI S12.43-1997, "Measurement of Sound Emitted by Machinery and Equipment at Workstations and Other Specific Positions" provides guidance for acquisition of noise levels from installed equipment which may be placed in the new facility.

## Conclusion

The design of engineering controls for noise abatement follows a formal process in which the first phase, *selection of the exposure criterion*, and the second, *measurement of employee exposure*, determines the complexity of the engineering controls which are required in a specific plant or operation.

Specific options for engineering controls are determined when the engineer analyzes the *source/path/receiver model* for reducing noise exposure. Options that are derived from this analysis enable the costs of mitigating employee exposure to the criterion level to be calculated.

Most important, noise control engineering is a science in which the trained acoustical engineer can predict the outcome of a noise control program. Any facility manager embarking on a noise control program should ask what the outcome will be and how it will be achieved. An independent acoustical consultant will provide the optimum solution to selection and design of engineering controls and save the employer money in the long run.

Lastly, when planning new facilities, renovating existing facilities, or adding equipment, it is always most cost effective to implement noise control before a problem exposure occurs. *It is much less costly to renovate with an eraser than with a jackhammer.* ◆

## Suggested Reading


1. American National Standards Institute (ANSI): American National Standard Measurement of Occupational Noise Exposure (ANSI S-12.19-106); American National Standard Specification of the Noise of New Machinery (ANSI S12.16-1992); American National Standard Measurement of sound emitted by machinery and equipment at workstations and other specific positions (ANSI S12.43-1997). New York City: ANSI.
2. Erdreich J: Noise Measurement. *McGraw-Hill Yearbook of Science and Technology*. 1992; pgs. 290-293.
3. Salmon V, Mills JS & Petersen AC: *Industrial Noise Control Manual*. Cincinnati: National Institute for Occupational Safety and Health (NIOSH). DHEW Report 75-183, 1975.
4. Occupational Safety and Health Administration: *Noise Control. A Guide for Workers and Employers*. Washington, D.C.: OSHA, 1980.



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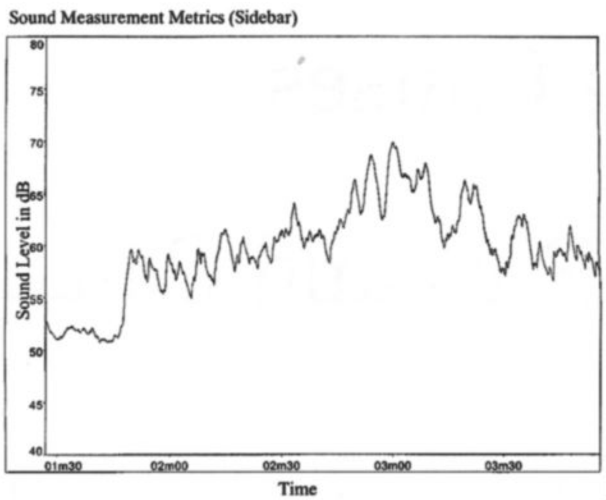
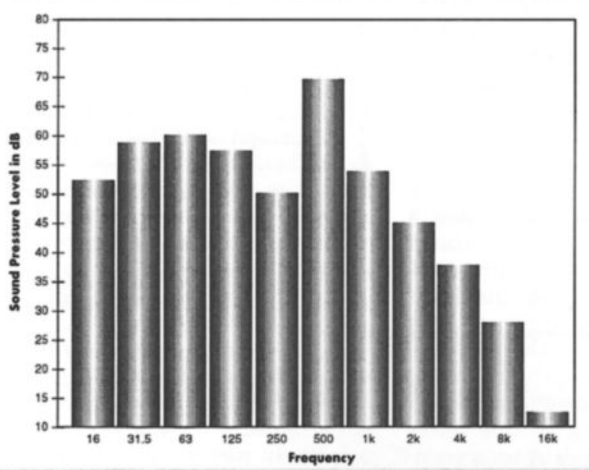
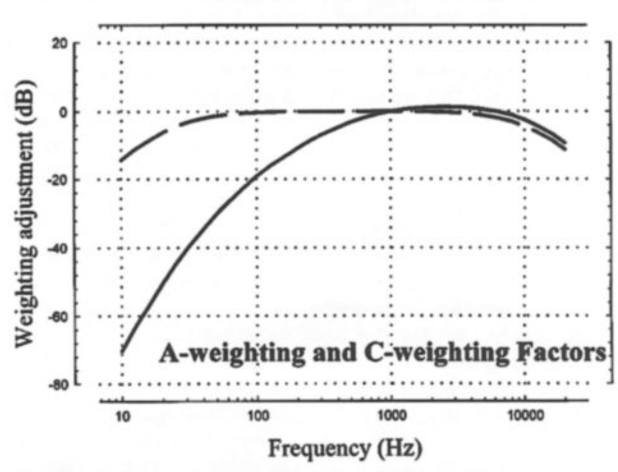
## Noise Exposure, Frequencies & Weighting




*Employee exposure to sound is a complex, time-varying phenomena shown above. The sound is comprised of many different frequencies. For the purpose of designing engineering controls, it is important to evaluate the different frequencies as shown below.*




*This is an octave band representation of the sound depicted in the figure above. It shows the frequencies of sound contained in the exposure. Note the strong component of energy at 500 Hz. This type of analysis is necessary for designing engineering controls.*




*Because the ear is less sensitive at low and high frequencies than in the mid-range for measurements related to the effect of sound on humans, a frequency network which reduces the importance of low frequencies is used. This circuit creates a meter response to different frequencies similar to that of the human hearing mechanism and is referred to as "A-weighting." The network is standardized and is contained in sound level meters and other acoustical instruments. Applying this filter to the measured sound results in the graph of A-weighted level versus time is shown in the previous figure. An alternate frequency response, "C-weighting," treats* all *audible frequencies as equally able to affect the ear.*