Noise and Vibration Control - Part 1

An Online Continuing Education Course for Engineers

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Introduction

This course is one of two volumes about controlling man-made noise in indoor and outdoor environments. This course provides guidance for the design and construction of those features related to noise and vibration control of mechanical equipment systems most commonly encountered. These two volumes should be studied in sequence to ensure a complete understanding of the material.

The first volume covers the basics of acoustics and vibration criteria for acceptable noise and vibration for indoor applications and how to calculate sound levels in indoor environments. Vibration control is only covered tangentially in this course as it relates to noise.

Volume II discusses how sound propagates out of doors and explains how to mitigate the impacts of outdoor noise. Volume II also covers noise control of HVAC systems for both indoor and outdoor components.

Noise level estimates have been derived for various types of mechanical equipment, and in some cases graded for power or speed variations of the noise-producing machines. The noise level estimates quoted in this course are typically a few decibels above the average. Therefore, these noise level estimates should result in noise control designs that will adequately "protect" approximately 80 to 90 percent of all equipment. It is uneconomical to design mechanical equipment spaces to protect against the noise of all the noisiest possible equipment; such overdesign would require thicker and heavier walls and floors than required by most of the equipment.

Before beginning the course let's look at the definitions of a few terms commonly encountered in the study of noise and vibration.

Definitions

Absorption. Conversion of acoustic energy to heat energy or another form of energy within the medium of sound-absorbing materials.

Absorption Coefficient. The ratio of sound energy absorbed by the acoustical material to that absorbed by a perfect absorptive material. It is expressed as a decimal fraction.

Average Sound Level and Average SPL. The arithmetic average of several related sound levels measured at different positions or different times, or both.

Decibel (dB). A unit for expressing the relative power level difference between acoustical or electrical signals. It is ten times the common logarithm of the ratio of two related quantities that are proportional to power.

Noise Criteria (NC). Octave band curves used to define acceptable levels of mechanical equipment noise in occupied spaces. Superseded by the Room Criteria (RC).

Noise Isolation Class (NIC). A single-number rating derived from measured values of noise reduction, as though they were values of transmission loss. It provides an estimate of the sound isolation between two enclosed spaces that are acoustically connected by one or more paths.

Octave Band. A range of frequencies whose upper band limit frequency is nominally twice the lower band limit frequency.

Octave-Band Sound Level. The integrated sound pressure level of only those sin-wave Pressure components in a specified octave band, for a noise or sound having a wide spectrum.

Residual Noise. The measured sound level which represents the summation of the sound from all the discrete sources affecting a given site at a given time, exclusive of the Background Noise or the sound from a Specific Sound Source of interest

Room Criteria (RC). Octave band criteria used to evaluate acceptable levels of mechanical equipment noise in occupied spaces.

Sound Power level (Lw or PWL). Ten times the common logarithm of the ratio of the total acoustic power radiated by a sound source to a reference power.

Sound Pressure Level (Lp or SPL). Ten times the common logarithm to the base 10 of the ratio of the mean square sound pressure to the square of a reference pressure.

Sound Transmission Class (STC). A single-number rating derived from measured values of transmission loss in accordance with ASTM E-413. It is designed to give an estimate of the sound insulation properties of a partition or a rank ordering of a series of partitions.

Sound Transmission Loss (TL). A measure of sound insulation provided by a structural configuration. Expressed in decibels, it is ten times the common logarithm of the sound energy transmitted through a partition, to the total energy incident upon the opposite surface.

Chapter 1: Basics of Acoustics

This chapter presents the basic quantities used to describe acoustical properties. For the purposes of the material contained in this document perceptible acoustical sensations can be generally classified into two broad categories, these are:

- *Sound.* A disturbance in an elastic medium resulting in an audible sensation. Noise is by definition "unwanted sound".

- *Vibration.* A disturbance in a solid elastic medium which may produce a detectable motion.

Although this differentiation is useful in presenting acoustical concepts, in reality sound and vibration are often interrelated. That is, sound is often the result of acoustical energy radiation from vibrating structures and, sound can force structures to vibrate. Acoustical energy can be completely characterized by the simultaneous determination of three qualities. These are:

- *Level or Magnitude.* This is a measure of the intensity of the acoustical energy.

- *Frequency or Spectral Content.* This is a description of an acoustical energy with respect to frequency composition.

- *Time or Temporal Variations.* This is a description of how the acoustical energy varies with respect to time.

The subsequent material in this chapter defines the measurement parameters for each of these qualities that are used to evaluate sound and vibration.

Decibels

The basic unit of level in acoustics is the "decibel" (abbreviated dB). In acoustics, the term *level* is used to designate that the quantity is referred to some reference value, which is either stated or implied.

The *decibel* (dB), as used in acoustics, is a unit expressing the ratio of two quantities that are proportional to power. The decibel level is equal to 10 times the common logarithm of the power ratio; or

$$\mathbf{dB = 10\log(\frac{P_1}{P_2})}$$

Where,
P_2 = The absolute value of the power under evaluation.
P_1 = Is an absolute value of a power reference quantity with the same units.

If the power P_1 is the accepted standard reference value, the decibels are standardized to that reference value. In acoustics, the decibel is used to quantify sound pressure levels that people hear, sound power levels radiated by sound sources, the sound transmission loss through a wall, and in other uses, such as simply "a noise reduction of 15 dB" (a reduction relative to the original sound level condition). Decibels are always related to logarithms to the base 10, so the notation "10" is usually omitted. It is important to realize that the decibel is in reality a dimensionless quantity (somewhat analogous to "percent"). Therefore when using decibel levels, reference needs to be made to the quantity under evaluation and the reference level. It is also instructive to note that the decibel level is primarily determined by the magnitude of the absolute value of the power level. That is, if the magnitudes of two different power levels differ by a factor of 100 then the decibel levels differ by 20 dB.

In many cases cumulative effects of multiple acoustical sources have to be evaluated. In this case the individual sound levels should be summed. Decibel levels are added logarithmically and not algebraically. For example, 70 dB plus 70 dB does not equal 140 dB, but only 73 dB.

Decibel values may be summed using,

$$\mathbf{L_{SUM} = 10\ Log\left[10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + \cdots + 10^{\frac{L_{pn}}{10}}\right]}$$

In the special case where decibel levels of equal magnitudes are to be added, the cumulative level can be determined by,

$$\mathbf{L_{SUM} = L_p + 10\ log\ (n)}$$

Where,
n = the number of sources, all with magnitude Lp.

In some case it is necessary to subtract decibel levels. For example if the cumulative level of several sources is known, what would the cumulative level be if one of the sources were reduced? Decibel subtraction is given by,

$$\mathbf{L_{Diff} = 10\ Log\left[10^{\frac{L_{p1}}{10}} - 10^{\frac{L_{p2}}{10}}\right]}$$

Strictly speaking decibels should be averaged logarithmically not arithmetically. Use the following equation for decibel averaging,

$$\mathbf{L_{Avg} = 10\ Log}\left[\frac{\mathbf{10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + \cdots + 10^{\frac{L_{pn}}{10}}}}{\boldsymbol{n}}\right]$$

Sound Pressure level (Lp or SPL)

The ear responds to sound pressure. Sound wav[illegible] [illegible]ons of pressure just above and below atmosph[illegible] [illegible]ge on the ear, and sound is heard. A soun[illegible]

The sound pressure leve[illegible]

Where,
p = the absolute level of th[illegible]
p_{ref} = the reference pressu[illegible]

Unless otherwise stated the [illegible] s) sound pressure. This equation is also writte[illegible]

$$[illegible]\ \mathbf{og}\left[\left(\frac{[illegible]}{\mathbf{P_{ref}}}\right)\right]$$

Although both formulas are correct, it is instructive to consider sound pressure level as the log of the pressure squared. This is because when combining sound pressure levels, in almost all cases, it is the square of the pressure ratios (i.e. $(\frac{P}{P_{ref}})^2$'s) that should be summed not the pressure ratios (i.e. not the $\{\frac{p}{P_{ref}}\}$'s). This is also true for sound pressure level subtraction and averaging.

Sound pressure level (SPL), expressed in decibels, is the logarithmic ratio of pressures where the reference pressure is 20 micro-Pascal or 20 uPa. This reference pressure represents approximately the faintest sound that can be heard by a young, sensitive, undamaged human ear when the sound occurs in the frequency region of maximum hearing sensitivity, about 1000 Hz. A 20 uPa pressure is 0 dB on the sound pressure level scale. In the strictest sense, a sound pressure level should be stated completely, including the reference pressure base, such as "85