IH for the CSP 4: Sound Pressure Levels

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Abstract

The sound level meter, SLM, is used to measure sound pressure levels, SPL's, on decibel scales. In general, a Bell (named for Alexander Graham Bell) scale is the log base 10 of the ratio of some measurement divided by a reference value. A decibal is one tenth of a Bell. Three scales are commonly used for sound pressure levels. They are called the linear scale (measured in dB), the A-weighted scale (measured in dBA), and the C-weighted scale (measured in dBC). The linear scale is directly related to the mean square pressure differential, p^2, by the following equation,

$$SPL = 10 \log \left[\frac{p^2}{p_0^2} \right] , \qquad 1$$

where p_0 = 20 μPa (micro Pascal) is the reference level. The linear scale is the best measure of the amplitude of the sound wave. The human ear, however, does not perceive sounds with the same amplitude as having the same "loudness" if they are of different frequencies. Weighted scales were devised so that noises which sounded equally as loud to the human ear would have the same sound pressure levels, regardless of frequency. The A scale best approximates human hearing at low sound pressure levels. The C scale best approximates human hearing at high sound pressure levels. There is a B scale for intermediate sound pressure levels, but this scale is not used in Industrial Hygiene,

For a pure tone (only one frequency present) a sound pressure level on the linear scale is converted to the A-weighted scale by adding the A-weighting factor for that frequency. The sound pressure level of a pure tone on the linear scale is converted to the C-weighted scale by adding the C-weighted factor for that frequency. A- and C-weighted factors are show below for selected frequencies.

Frequency	A-weighted	C-weighted
31.5 Hz	-39.4	-3.0
63 Hz	-26.2	-0.8
125 Hz	-16.1	-0.2
250 Hz	- 8.6	0.0
500 Hz	- 3.2	0.0
1 kHz	0.0	0.0
2 kHz	+ 1.2	-0.2
4 kHz	+ 1.0	-0.8
8 kHz	- 1.1	-3.0

Most sounds are composed of many frequencies. That is, the sounds we hear, human speech, music, industrial noise, can be made by adding together many pure tones. For normal sounds, or composite tones, converting scales is more complicated. We think of dividing the sound into narrow ranges of frequencies called the octave bands. Each octave band represents all frequencies within that narrow range. The upper end of an octave band is always twice the lower end. Octave bands are labeled by their geometric mean frequency. For example, one octave band represents all frequencies from 707 Hz to 1414 Hz. That band is called the 1000 Hz octave band. The frequency 1000 Hz is called the geometric mean because,

$$\frac{707\ \text{Hz}}{1000\ \text{Hz}} = \frac{1000\ \text{Hz}}{1414\ \text{Hz}}$$

The selected frequencies in the table above are the geometric means for the most commonly used octave bands. To convert a sound pressure level from the linear scale to the A-weighted scale when a broad range of frequencies are present, the A-weighted factor for the geometric mean frequency for each octave band is added to the sound pressure level for that band. The total sound pressure level is then given by the "sum" of the sound pressure levels in each band.

When "adding" sound pressure levels, it must be remembered that p^2 is the physically significant variable. When sound pressure levels are added, the total p^2 is the sum of the initial p^2's. The total sound pressure level is not the algebraic sum of sound pressure levels. An expression for the sum of two sound pressure levels, SPL_1 and SPL_2 is obtained by solving equation 1 for p_1^2 and p_2^2 , adding and again applying equation 1 to get a sound pressure level from the total mean square pressure differential. After simplifying, the result is,

$$SPL_{TOT} = 10 \log [\, 10^{SPL1/10} + 10^{SPL2/10} \,] . \qquad 2$$

This result can be extended to add any number of sound pressure levels. For every sound pressure level to be added, there will be one additional term of ten to the power of one tenth the sound pressure level.

The logarithm of a product is the sum of the logarithms. If two equal sound pressure levels are combined, equation 2 becomes,

$$SPL_{TOT} = 10 \log [\, 2 (10^{SPL}/10)] = 10 \log 2 + 10 \log [10^{SPL/10}]$$

$$= 3 + SPL .$$

For every doubling of energy of a sound wave, the sound pressure level increases by 3 dB.

Suppose the output from the grinding wheel alone is 85 dBA as measured at a given location, the output from the sander is 84 dBA at the same location, and the output from the drill press, again to this same location, is 87 dBA. The total sound pressure level at that location, if all three machines are in use at the same time is, SPL_3 , is given by,

$$SPL_3 = 10 \log [10^{8.5} + 10^{8.4} + 10^{8.7}] = 90.29 \text{ dBA} .$$

Similarly, if a source of sound is removed, the resultant sound pressure level can be predicted by subtracting a term of ten to the power of one tenth the sound pressure level, or,

$$SPL_{RES} = 10 \log [10^{SPL/10} - 10^{SPL'/10}] , \qquad 3$$

where SPL_{RES} is the resultant sound pressure level with the source removed, SPL is the total sound pressure level before removal, and SPL' is the sound pressure level due only to the source to be removed. Suppose the total sound pressure level in a wood working shop is 91 dBA. This exceeds the level allowed by OSHA. There is one older carving machine known to contribute 84 dBA by itself. The anticipated sound pressure level if that machine were removed from service, $SPL_{W/O}$, is given by,

$$SPL_{W/O} = 10 \log [10^{9.1} - 10^{8.4}] = 90.03 \text{ dBA} .$$

Notice, the removal of an 84 dBA source reduced the SPL by less than 1 dBA, **not** by 84 dBA.

Often it is desired to determine the sound pressure level due to only one source. Workplace conditions, however, do not allow for all other work to stop while making this measurement. The sound pressure level with the source in question turned off is the background noise. The background can thought of as one source. The sound pressure level can be measured with the target source on, and equation 3 used to determine the resultant SPL if the background could be "turned off." Suppose the background (with the target source off) was 89 dBA. With the source on, the SPL is 88 dBA. The sound pressure level of the target source alone, SPL_{TGT}, would be,

$$SPL_{TGT} = 10 \log [10^{8.9} - 10^{8.8}] = 82.13 \text{ dBA} .$$

The sound level meter is equipped with internal circuitry which will automatically add the A- and C-weighted factors and read out the sound pressure level as would be calculated for the A- and C- scales. When the instrument is set on “linear” or “lin” it will read sound pressure levels on the linear scale (in dB). When the instrument is set on “A” or “C” it will read sound pressure levels on the A-weighted and C-weighted scales respectively.

The octave band analyzer is a device which attaches to the sound level meter. When the sound level meter is set to “ext,” “external,” or “octave,” the sound pressure level read by the meter is “weighted” by the octave band analyzer. The octave band analyzer is designed to subtract very little from sound pressure levels with frequencies within the band on which it is set, and subtract greatly from sound pressure levels outside that band. The result is that the meter will, in effect, read out the sound pressure level due to noise with frequencies in the selected octave band only. It should be noted that this weighting by the octave band analyzer is not perfect. A low sound pressure level may be indicated in an octave band even if the frequencies present in the sound are located only in nearby bands.

Consider the following example. Suppose an industrial hygienist made the following sound level measurements for your employer. Because of the available instrumentation or because he just didn't know any better, the IH only measured levels on the linear scale (in dB). Since you are knowledgeable about the weighting scales, the employer asked you to convert these readings to the A- weighted scale.

Frequency	SPL
250 Hz	87 dB
500 Hz	89 dB
1 kHz	27 dB
2 kHz	67 dB

Total SPL = 91.14 dB

Before converting to the A-scale, a little explanation of these measurements is presented. The total sound pressure level was 91.14 dB. The octave band analyzer was used to "break up" this total sound into four octave bands (usually 9 are used). For instance, the 500 Hz band includes all frequencies from 353 Hz to 707 Hz. If all sources of sound with frequencies below 353 Hz or greater than 707 Hz could be damped out of the total noise, the resulting noise would have the SPL shown for the 500 Hz octave band, 89 dB. If the four sound pressure levels for the octave bands are added together using equation 2,

$$SPL_{TOT} = 10 \log [10^{8.7} + 10^{8.9} + 10^{2.7} + 10^{6.7}] = 91.14 \text{ dB},$$

the total that was measured, 91.14 dB, is obtained.

Because the human ear responds differently to different frequencies, it is not possible to look simply at the total SPL and convert to the A-weighted scale. The noise must be broken down into the octave bands. The sound pressure level in each octave band is corrected separately, and the weighted SPL's are added back together. The SPL for the 250 Hz band was 87 dB. The A-weighted factor for this band is -8.6. The A-weighted SPL for the 250 Hz band is 87 + (-8.6) = 78.4 dBA. Notice the change in units. Once a sound pressure level is converted to the A scale, the units change from dB to dBA. Similarly, the SPL for the 500 Hz band is 89 + (-3.2) = 85.8 dBA, on the A-weighted scale. The 1000 Hz (1 kHz) band is the reference band. All scales are the same at this frequency and no correction is done (zero is added), leaving 27 dBA. Finally, the SPL in the 2 kHz (2000 Hz) octave band is 67 + 1.2 = 68.2 dBA. These four SPL's on the A-weighted scale are then added using equation 1,

$$SPL_A = 10 \log [10^{7.84} + 10^{8.58} + 10^{2.7} + 10^{6.82}] = 86.59 \text{ dBA} .$$

Results are summarized in the table below.

Frequency	Linear	A Factor	A Scale
250 Hz	87 dB	-8.6	78.4 dBA
500 Hz	89 dB	-3.2	85.8 dBA
1 kHz	27 dB	0	27.0 dBA
2 kHz	67 dB	1.2	68.2 dBA
Total SPL	91.14 dB		86.59 dBA

Sound pressure levels on the C-weighted scale are calculated in exactly the same manner except that a different set of weighting factors is used.

The sound level meter must be calibrated before and after each use. If the meter will be used with the octave band analyzer, it must be calibrated with the octave band analyzer attached. For the sound level meter, calibration means only that the instrument is given a sound of known strength and is checked to be sure it reads the level it should. The Occupational Safety and Health field is continually concerned with litigation. Employees often sue their employers for a wide range of illnesses, both real and imagined. Workman's Compensation claims and OSHA compliance also have legal aspects. For any Industrial Hygiene survey to have legally defensible results, proper calibration of instruments must be meticulously documented. The time, date, and place of calibration and sampling must be recorded. The make, model, and serial numbers of all instruments (sound level meters and octave band analyzers) and calibrators must also be recorded. The sound pressure levels read by the instrument must be recorded as well as the rated output of the calibrator.