2. NOISE PROBLEM ANALYSIS

DOES A NOISE PROBLEM EXIST?

Is the level of noise in your plant hazardous? Annoying? To find out, try to talk with someone in the noisy area of the plant. If you can talk comfortably with someone 1 m away, there is probably not enough plant noise at that position to damage hearing. But if you, or others, must shout to be heard or understood at close distances (between 20 to 40 cm), plant noise at that position probably can cause hearing loss, and you should have the sound levels there measured with suitable instruments.

How about noise traveling out of the noisy plant area? If personnel in other parts of the plant complain, you should investigate their complaints, and measure the levels of the sound they hear. If plant neighbors complain, or if local authorities say the sound exceeds applicable noise ordinances, a problem may exist and measurements are called for.

Once appropriate, accurate sound level measurements are made, measured values should be compared with the noise regulation or sound level criterion correct for the situation. ("Criterion" here means a target for an acceptable sound level for a specific environment.)

When you are seeking compliance with OSHA noise regulations, the sound level regulation is a function of both *sound level* and *daily exposure time.* If the measurements reveal an excessive combination of sound levels and exposure times, a noise problem exists.

For noise intrusion into other parts of a plant or building, use the same approach. Measure sound levels, compare them with well-authenticated criteria, and determine whether a problem exists and what the solution may be.

Even in the absence of complaints from plant neighbors, a local noise ordinance may dictate the allowable sound level limits. (Be aware that a local ordinance may designate different levels for daytime and nighttime plant operation.) When no local ordinance exists and neighbors are saying the sound from the plant is "too loud," your best move is to make sound level measurements in the community – first, when the plant is not operating, second, when it is. If you find that plant noise is well above the "ambient," or background sound in the community, a community noise problem quite probably exists. A sound that causes annoyance or offense may be affected by many factors, all adding to its complexity. A tonal sound, such as the "whine" of a fan, or an intermittent or impulsive sound, such as those made by a jackhammer, a pile driver, a steam vent blowing off, or an outdoor P.A. system, is usually more identifiable – and more objectionable – than a sound that has less noticeable characteristics.

A noise problem, then, may manifest itself in one or both of two ways:

- By the *subjective* response of people who are disturbed by the noise
- By *objective* measurements of the sound levels and comparison of those values with noise regulations or noise criteria generally regarded as applicable to the situation.

To understand sound measurements, characteristics, and interpretations, you must have a general knowledge of the theory and terminology used in acoustics and noise control. The next two subsections summarize this material briefly.

What Is Sound?

Key words:

Sound

Frequency

Wavelength

Hertz

Tonal

Harmonics

Fundamental Frequency

Broadband Sound

Octave Bands

Root-Mean-Square (rms)

Sound Pressure

Decibels

Sound Pressure Level

Pascal

Sound is a physical occurrence. It is caused by minute pressure variations that are transmitted (invisibly) by wave motion. The propagation of sound is analogous to the disturbance that is transmitted along the length of a long stretched spring (fixed at both ends), when a section of the spring at one end is repeatedly and regularly compressed and released. The compressed and stretched parts of the resulting wave traveling along the spring are like the compressed and rarified parts of a sound wave traveling through the air. The rate at which the spring is periodically compressed and released (or at which the air is compressed) becomes the *frequency* of the wave. The spacing between consecutive disturbances on the spring becomes the *wavelength*.

In the spring, as in air, the speed of travel of the disturbance depends only on properties of the medium through which it travels. Speed, frequency, and wavelength are interrelated by the following equation:

frequency = speed of disturbance ÷ wavelength.

Acousticians write this relationship as:

$$f = c/\lambda. \tag{2.1}$$

Imagine the stretched spring again. With a fast rate of compressing and releasing the spring, there will be only short distances between successive disturbances traveling along the spring. With a low rate of compressing and releasing the spring, there will be relatively long distances between successive disturbances traveling along the spring. In other words, for sound in air (as well as for the spring), high frequencies have short wavelengths and low frequencies have long wavelengths. This fact is borne out by Equation 2.1.

Sound moves in air at normal room temperature and pressure at a speed of about 340 m per sec. Frequency is expressed as oscillations or vibrations or events per second, called *Hertz*, abbreviated Hz (formerly identified by the unit "cycles per second" or cps). Wavelength may be quoted in meters, feet, or inches. Figure 2.1 is a wavelength chart.

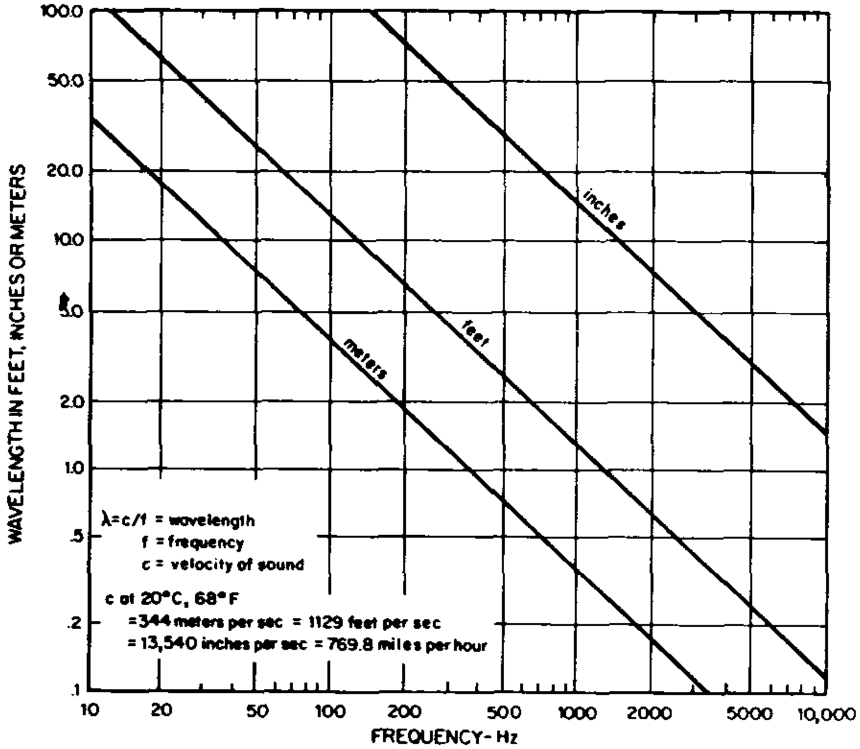

Figure 2.1. Frequency-wavelength chart for sound in air at normal temperature and pressure.

If you were to hear a sound at a single frequency, it would sound *tonal*, like the sound of a vibrating tuning fork. Most sounds actually are composites of many frequencies. Notes played on musical instruments, for example, contain not only a dominant "fundamental frequency," but also additional tones having multiples of the fundamental frequency (overtones or *harmonics*). For example, "A below middle C" on a piano keyboard has a *fundamental frequency* of about 440 Hz, but its sound also contains tonal components at 880, 1320, 1760, 2200, 2640 Hz, and so on, as conceptualized in Figure 2.2.

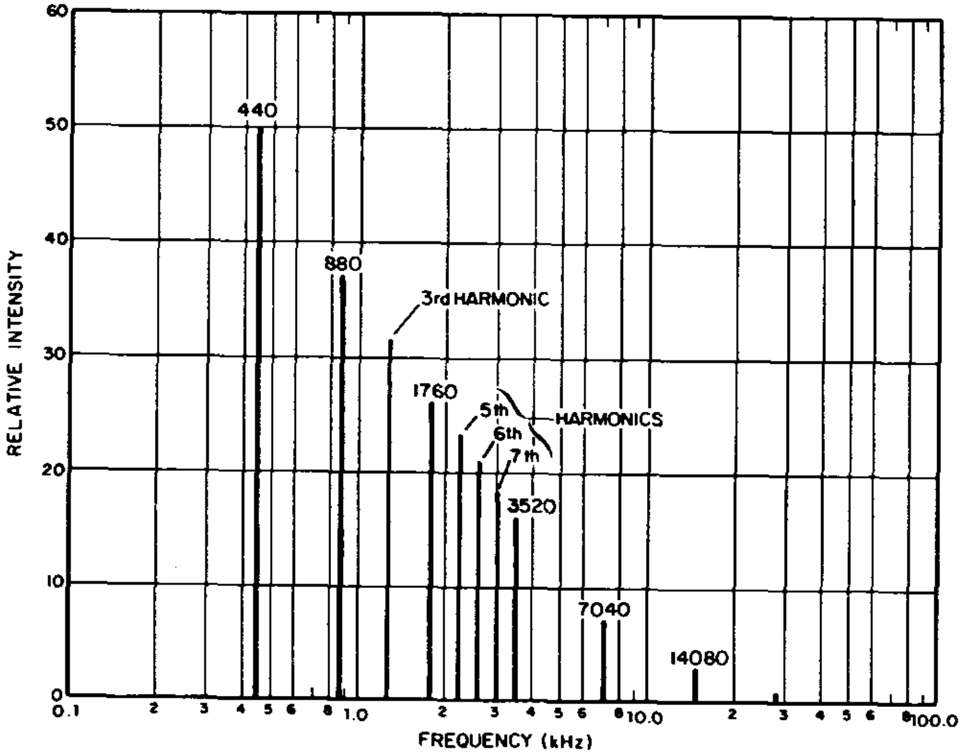

Figure 2.2. Frequency component of musical note.

Many typical sounds do not have tones at fixed frequencies, i.e., an automobile or truck driving along a street, an air jet or air leak from a compressed air supply, the "bang" of a punch press, or the combustion roar of a furnace. These sounds have short, repeated, random bursts of noise at all frequencies across the full range of human hearing (say 16 Hz to 16,000 Hz, more or less). Such sounds are termed *"broadband,"* but their noise composition can still be broken down into the frequency contents of the noise. Most often, values for the noise contained within adjacent bands of frequencies (called *octave bands*) are used to display the frequency composition of a sound. Figure 2.3 illustrates the concept. The air leak produces mostly high-frequency "hissy"

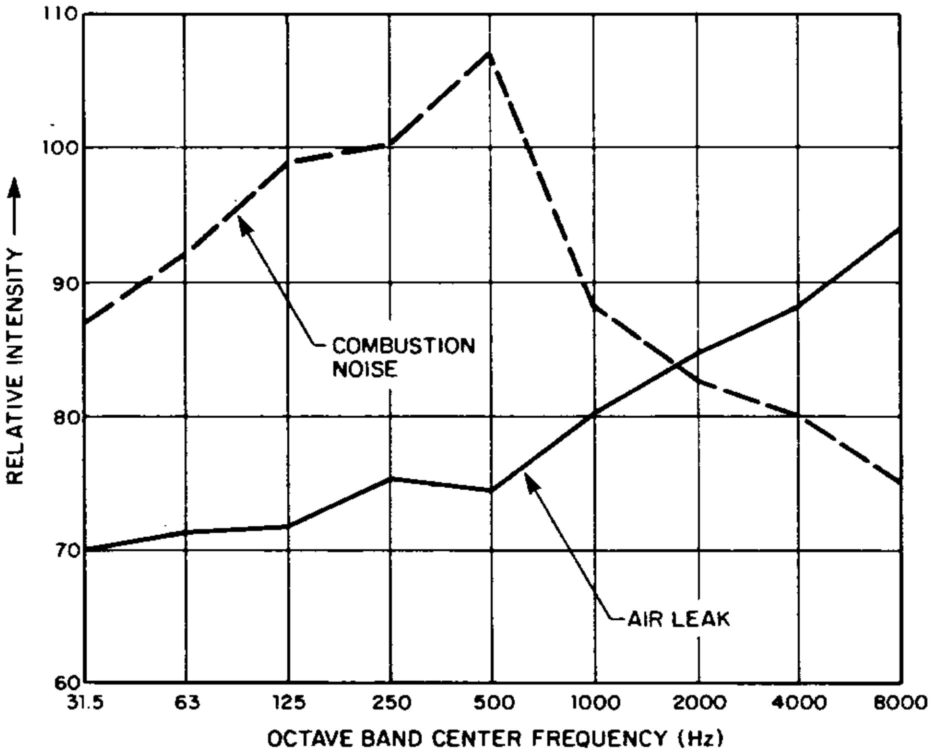

Figure 2.3. Frequency composition of two common industrial sounds.

sounds; the furnace combustion produces mostly low-frequency "rumbles." Such spectra (frequency breakdowns) are a kind of signature of the noise. Sometimes more detailed spectra are used in noise analysis. The values of the frequency content would then be plotted in one-third octave bands or one-tenth octave bands, for example.

The frequency content of noise is very important because hearing damage is related to frequency, and the effectiveness of noise control treatments depends on frequency.

Think of the vibrating stretched spring again. The parts of the coil vibrating back and forth move only through short distances. Similarly, in the sound wave, air particles vibrate back and forth only through very short distances (perhaps a few ten-thousandths of a millimeter or a few millionths of an inch); the air particles do not travel all the way across the room or across a field. Yet they transmit their energy by setting adjoining air particles into vibration, and those, in turn, pass the vibration on to their neighboring air particles. Air is a nearly perfectly elastic medium, and there is practically no loss of energy as these particles transmit their vibration from one to another across the room at the speed of sound.

As the air particles vibrate, momentary tiny fluctuations occur in the atmospheric pressure. It is these pressure changes that our ears detect as sounds or that a microphone responds to. The *sound pressure* changes alternatively positive and negative relative to atmospheric pressure, as the air is compressed and rarified.

It is necessary to be able to apply numbers to the pressure changes that occur. The best quantity to use is the average pressure. But if we tried to average the sound pressure changes that occur at a particular point and over a particular time interval, we would find the average always equal to atmospheric pressure - all the positive pressure fluctuations are exactly counterbalanced by the negative ones. Thus, in place of a simple average, the instantaneous pressures are first squared, then square-rooted before making the average. This procedure gives a positive valued quantity to a sound pressure. This is what is meant by the *root-mean-square* (rms) value of the sound pressure.

A very weak sound may have an rms sound pressure that is very small compared to atmospheric pressure; in fact, the rms sound pressure of a barely audible sound at 1000 Hz (in the frequency region where we hear best), in a very quiet environment, is about 0.0000000002 or 2×10^{-10} atmosphere, obviously a small pressure. A very loud sound could have an rms sound pressure of over 0.001 atmosphere. These numbers not only represent a large range of possible pressure variation, but also involve some very unwieldy numbers.

To simplify the numbers, while relating them to a meaningful scale, rms sound pressures are quoted in terms of *decibels*. (A meaningful scale is one that bears some relation to the apparent "loudness" of the noise.) Decibels are logarithmic values, and they are based on a reference starting point. The starting point, 0 decibels, is the rms sound pressure corresponding to the weakest audible sound mentioned above (0.0000000002 atmosphere). This is the weakest sound that can be heard by a large proportion of people (when tested under ideal listening conditions). All subsequent sound pressures (unless otherwise noted as such) are rms sound pressures and are referred to that standard reference pressure.

The decibel (abbreviation: "dB"), is the unit for expressing sound pressure level relative to 2×10^{-10} atmosphere. In the metric system, this reference pressure is 2×10^{-5} Newton/m^2. The unit "pascal" is defined as 1 N/m^2, so the sound pressure level reference is currently expressed as 2×10^{-5} pascal or 20 micropascal. Thus, to be technically correct, one should say, "The sound pressure level is 75 decibels relative to 20 micropascal." Since this is a universally recognized pressure base, it is often not quoted, however, and one usually says, "The sound pressure level is 75 dB."

The word *level* is used to designate that the rms pressure is relative to the universal base sound pressure. The sound pressure level (SPL) for any measured sound is defined by:

$$\text{SPL (in decibels)} = 10 \log \frac{(\text{rms sound pressure measured})^2}{(20 \text{ micropascal})^2}$$

or

$$= 20 \log \frac{(\text{rms sound pressure measured})}{(20 \text{ micropascal})} .$$

In practice, a sound level meter is calibrated to read decibels relative to 20 micropascal, so a person is seldom aware of the rms pressure of the actual sound (that is, how many millionths of an atmosphere it is, or how many Newtons per m^2, or lb per $in.^2$, or dynes per cm^2). Yet we are aware that very quiet sounds (a quiet whisper, or the rustling of grass in a very slight breeze) may range from 10 to 20 dB, while very loud sounds (a nearby diesel truck or an overhead aircraft shortly after takeoff or a loud clap of thunder) may range from 85 dB to over 130 dB. Instantaneous sound pressure levels of 160 dB can rupture the eardrum, and the risk of permanent hearing impairment increases as a function of sound levels above 80 dB.

"dBA" vs "dB"

Key words:

Frequency Weighting Networks

A-Weighted Sound Levels

L_p

L_A

Anyone involved in noise control quickly learns a basic concept: People's *response* to sound is frequency-dependent. We hear best at frequencies around 500 to 5000 Hz, for example, and perhaps for this reason, we are most annoyed or disturbed by noise in that range. In addition, we know that high sound levels and long exposure times to sounds in this same frequency range contribute to hearing loss. These facts have ramifications on the *effects* of sound, and, consequently, there is usually a need to know about the frequency distribution contained within a given sound being investigated, and also a need to place emphasis on those frequencies having the greatest effects.

The typical sound level meter has three different *frequency-weighting networks,* identified as the A-, B-, and C-scale networks. Their frequency responses are given in Figure 2.4. Extensive studies have shown that the high-frequency noise passed by the A-weighting network correlates well with annoyance effects and hearing damage effects of the noise on people. Consequently, sound pressure levels, as measured with the A-scale filter, are used in various rating systems for judging the annoyance of noise and for evaluating the hearing damage potential of high sound levels and exposures. (The term noise *exposure* involves both sound levels and the duration of exposure time to those sound levels; it is discussed in more detail later.) The OSHA noise regulation incorporates *A-weighted sound levels* for this reason. (Note that when weighting factors are applied in determining the level of a noise, the term "pressure" is dropped from the expression "sound pressure level.")

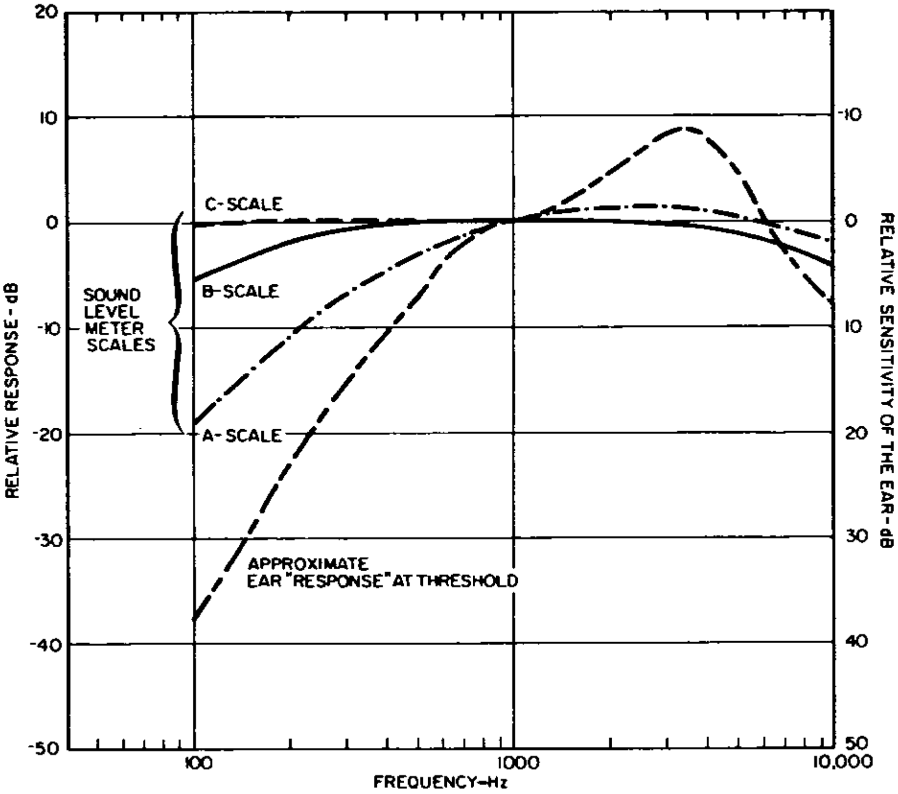

Figure 2.4. Response characteristics of weighting scales and of ear at threshold.

The fourth curve in Figure 2.4 shows the approximate relative sensitivity of the average ear (as a function of frequency) when tested for hearing weakest possible sounds ("threshold"), confirming the high-frequency region of highest sensitivity.

Table 2.1 gives the octave-band frequency response of the A-weighting network, as taken from Figure 2.4. When the sound level meter is switched to the "A" position, the meter gives a single-number reading that adjusts the incoming noise at the microphone in accordance with this filter response and then indicates a numerical value of the total sound passed by this filter. The resulting value is called the A-weighted sound level, and it is expressed in units designated *dBA*. In the literature, L_p is used to denote sound pressure level in dB, and L_A is used to denote A-weighted sound level in dBA.

Table 2.1. Octave-band frequency characteristics of the A-weighted sound level meter filter.

Octave-band center frequency (Hz)	Filter response (dB)
31.5	-39.5
63	-26
125	-16
250	- 8.5
500	- 3.0
1000	0
2000	+1.0
4000	+1.0
8000	-1.0

OSHA REGULATIONS: WORKER NOISE EXPOSURES

Key words:

Noise Exposures	*Daily Noise Dose*
Noise Emissions	*Impulse Sounds*
Noise Dose	*Peak Sound Pressure Level*
Partial Noise Dose	*Slow Meter Response*

The Occupational Safety and Health Administration (OSHA), by authority granted under the Occupational Safety and Health Act of 1970, has established regulations for worker *noise exposures*. OSHA regulations state that occupational noise exposures should not exceed 90 dBA for an 8-hr work period. For briefer time periods, higher sound levels are permitted, as shown in Table 2.2. It is quite clear that personnel must be present to hear a sound before the regulation is applicable. Thus, a machine producing 120 dBA

Table 2.2. Permissible noise exposures.

Duration per day in hours	Maximum allowable sound level (dBA)
8	90
6	92
4	95
3	97
2	100
1	105
1/2	110
1/4 or less	115

is *not* in violation if no one is around the machine to hear it. Do not confuse measures of sound *produced* by equipment (*noise emissions*) with measures of sound *received* by a worker (*noise exposures*).

In many plant situations, sound levels may vary during the day. Machines may operate in various modes, and the sound levels may change accordingly. Workers may move around their machines or to different parts of the plant. Production sequences and their resulting sound levels may change during the day or workshift.

Thus, there is a need to account for time-varying noise in determining noise exposure. The OSHA regulation deals with exposure to changing sound levels by application of the *noise "dose"* concept. Exposure to any sound level at or above 90 dBA results in the worker incurring a *partial* (fractional or incremental) *dose* of noise. The more intense the noise and the greater its duration, the greater the partial dose. The sum of all the partial doses may be calculated to produce the total or *daily noise dose,* which should not exceed a specified value. Each fractional dose from exposure to a given sound level is equal to:

$$\frac{\text{the time actually spent at the sound level}}{\text{the allowed time for that sound level}}$$

The allowed time can be found from Table 2.2 (which is taken from the regulation), or it may be found, from the following equation, for sound levels not listed in the table:

$$\text{allowed time} = \frac{480}{2^{0.2(L_A-90)}} \quad , \tag{2.2}$$

where L_A is the actual A-weighted sound level at the operator position.

The total noise dose for the day is the sum of all partial doses, as in the equation:

$$D = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \cdots + \frac{C_n}{T_n} , \tag{2.3}$$

where each C_n is the actual exposure time for each sound level and its corresponding T_n is the allowed exposure time from Table 2.2 or Equation 2.2 for that sound level. With the OSHA limit at 90 dBA for an 8-hr day, the total dose in Equation 2.3 should not exceed 1.00. Note that if the OSHA 8-hr noise limit were changed to some other value N (such as 85 dBA, for example), Equation 2.2 would become

$$\text{allowed time} = \frac{480}{2^{0.2\,(L_A - N)}} ,$$

and total noise dose would still be calculated in accordance with Equation 2.3.

Under the regulation in effect at the time of publication of this *Manual*, where 90 dBA is the basic limit, sound levels under 90 dBA are not applicable in computing partial doses. In other words, any length of exposure time at 89 dBA is permitted and is not counted as contributing to the total daily dose.

As an example for determining whether a noise exposure is in compliance with the OSHA noise regulation, suppose an operator is exposed to the following daily sound levels:

105 dBA for 15 min

92 dBA for 1.5 hr

95 dBA for 2 hr

85 dBA for 4.25 hr

In accordance with the 90-dBA/8-hr limit in effect at the time of publication of this *Manual*,

$$D = \frac{0.25}{1} + \frac{2}{4} + \frac{1.5}{6} + \frac{4.25}{\infty}$$

$$= 0.25 + 0.5 + 0.25 + 0$$

$$= 1.0 \text{ (at or below 1.00, so it is acceptable).}$$

To determine if the regulation is satisfied, then, a person's mixed exposure to a variety of sound levels must be considered as follows: (1) Sort the exposure into actual time spent at the various sound levels, (2) calculate the incremental doses for each sound level, (3) sum the incremental doses, and (4) compare the total with the allowable total daily noise dose, which is equal to 1.00.

Clearly, much analysis is required for complex noise exposures, especially for noise exposures that may vary on a day-to-day basis as well as on an hour-to-hour or minute-to-minute basis. The OSHA regulation is not restrictive as to the method that can be employed to make the noise exposure determination, and some equipment is available that enables the evaluation to be made automatically or semiautomatically. Several exposure evaluation methods are discussed later.

The present regulation contains a few additional stipulations:

- No exposure may exceed 115 dBA. A violation occurs if any exposure is greater than 115 dBA, regardless of how brief it is.

- No sound *impulses* may exceed 140-dB *peak* sound pressure level. Impulses, ill-defined in the regulation, are considered sounds with peaks occurring at intervals of 1 sec or more. Special equipment is needed to evaluate the peak sound pressure levels, which are unweighted measures of the maximum instantaneous pressure variation, as contrasted with measures of the rms value of the pressure variation.

- Sound levels are to be determined using a *"slow response"* setting on the meter. This reference is to the averaging time of the meter circuitry of the instrument. The smaller the averaging time, the more closely the meter will trace actual pressure fluctuations. Slow response incorporates an averaging time of about 1 sec, and thus peak fluctuations in pressure within a given second become moderated and yield a lower average level.

HOW TO MEASURE SOUND

In the usual industrial noise situation, there will be two types of measurements:

(1) *Compliance measurements,* which are made in accordance with some relatively precise set of instructions, usually based on laws or regulations.

(2) *Diagnostic measurements,* which are used in engineering control of noise to help locate specific noise sources and determine their magnitudes, and to help select the types of controls needed, their locations, and the amount of reduction sought.

In this section, we discuss instrumentation and procedures for making compliance measurements and in the following sections, we discuss diagnostic measurements.

Compliance measurements are made in accordance with some relatively precise set of instructions, usually based on laws and regulations. The purpose is usually to determine the extent of compliance with the limits set forth in the laws or regulations. Thus, in an OSHA noise exposure compliance survey for industrial noise, the basic data will be the slow A-weighted sound levels measured at the ear location of the workers, together with the times spent at the sound levels encountered. From these data, the daily noise dose is calculated by means specified in the regulations.

Basic Instruments and Their Use

Sound Level Meter--

The chief instrument for noise measurements is the sound level meter (SLM), which should be a Type 1 (precision) or 2 (general purpose), made in accordance with American National Standard S1.4 (1971), "Specification for Sound Level Meters." The Type 2 instrument has broader tolerances on performance than the Type 1 instrument and is acceptable under the OSHA Occupational Noise Exposure regulations. It is usually less bulky, lighter, and less expensive than the Type 1 SLM. A sound level meter typically consists of a microphone, a calibrated attenuator, a stabilized amplifier, an indicating meter, and the designated weighting networks.

All SLMs are sensitive to rough handling and should be treated with care. Microphones, especially, are subject to damage if mishandled. Instruction booklets provided with the units should be read carefully to determine how the instrument should be operated and under what conditions the readings will be valid. The user should learn how to determine when battery power is too low and how to ensure that the instrument is reading the sound environment and not internal electrical noise or an overloaded condition.

When the sound levels are known to change very little throughout the working day, a simple SLM reading suffices for characterizing the noise environment. However, the reading must be taken properly. The standard procedure is to locate the microphone at the ear position of concern, but with the worker at least 1 m away. This is the "free-field measurement" that is preferred in American National Standard S1.13-1971, "Methods for the Measurement of Sound Pressure Levels." For a general standing position, the preferred microphone height is 1.5 m, for a seated worker, 1.1 m.

When it is necessary to make sound measurements that will withstand scrutiny in the courts, several criteria are important:

(1) The data should be obtained by a qualified individual (usually, a disinterested one, to avoid charges of bias).

(2) The instruments and measurement procedures used should conform fully with the applicable American National Standards. NIOSH provides a list of certified Type 2 sound level meters.*

(3) Instruments should be calibrated before *and* after each significant set of readings. If the calibration is out of tolerance, readings back to the previous calibration must be repeated.

(4) The calibration should be traceable to the National Bureau of Standards.

Obtaining reliable data depends on periodic calibration of the instruments. The preferred calibrators deliver an acoustical signal of known frequency and sound pressure level. Some calibrators provide a variety of signals of different frequencies and levels. To ensure that the calibrators are correct, it is advisable to own two units, to make frequent intercomparisons of both units on the same sound level meter, and, annually, to have one of the calibrators recalibrated by the manufacturer or a reliable instrument laboratory, requiring that the calibration can be traceable to the National Bureau of Standards.

The manufacturer's instructions for holding the SLM should be followed, as microphone positioning can influence the readings, especially close-in to a noise source. Most U.S.-made instruments are designed to read correctly when the axis of the microphone is at a particular angle to the direction the sound is traveling. Most instruments made in Europe are designed to be correct when the microphone is aimed at the source.

To have minimum interference from the body of the observer, position the microphone at least 1 m away from the observer, and position the observer to the side of the microphone (relative to the source of sound).

In general, do not spend time reading sound levels to tenths of decibels (even the best field meters are accurate only to ±1 dB). Considerable time can be saved, at virtually no cost to the accuracy of the work involved, by rounding off the meter reading to the nearest whole decibel.

Generally, you should first explore the region of interest before obtainining the final sound level for compliance measurements. Directional effects can sometimes change the reading a few decibels

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*NIOSH Technical Publication (awaiting clearance). NIOSH Certified Equipment.

in a short distance. One example is a noise source that is partially shielded by a machine structure, with the operator in and out of the acoustical shadow. Several readings may be needed to delineate completely the noise in the range of positions used by the worker in question.

For most industrial situations, a reading on the slow and A-scale settings is specified for compliance measurements. Despite the averaging properties of the "slow" setting and despite "whole decibel" determinations, industrial noise is often so variable that reading the meter becomes a problem. A suggested sampling method is to take readings, with the SLM set to slow response, every 15 sec for a period of 3 to 5 min, then calculate an average value.

When you are making a meter reading of a rapidly fluctuating noise, obtain the average meter deflection as follows:

- If the difference between average minima and average maxima is less than 6 dB, use the average of these two extremes.
- If the difference is greater than 6 dB, use the reading 3 dB below the average maxima.
- Record the range of readings, if they are over 6 dB, plus your comments on probable cause. Typical causes include machine cycling and very low-frequency pulsation from air handling equipment.

Some general advice applies to using the sound level meter.

- Wind or air currents can cause false readings. Use a wind screen with the microphone for any measurements when you can feel a wind or air current. The wind screen should be designed for use with the particular microphone.
- Vibration of the meter can distort readings. Do not hold the meter directly against a vibrating machine, and do not support a tripod-mounted SLM on a strongly vibrating floor or platform. Instead, hand-hold the meter so that vibration is not transmitted into the instrument.
- High room humidity or temperature can also be a problem. If condenser-type microphones are used for tests in high-humidity areas, keep a spare microphone in a dry place (a dry storage container) and alternate microphones (between the SLM and the dry storage container) whenever you hear popping sounds (if monitored by head phones) or when erratic needle deflections occur on the SLM.

- Magnetic distortion of the meter from adjacent power equipment can also cause problems. Magnetic fields usually drop off quickly with distance from a motor or transformer. Move the SLM far enough away from the electric-magnetic equipment to be sure that the needle reading is attributable to the acoustic signal.

- Barriers or walls can obstruct sound and reduce sound levels or, by reflection, can increase sound levels. Avoid measurement positions where barriers or walls can alter the sound field, unless the position is clearly at the normal location of the operator.

- Avoid dropping the meter when it is hand-held; keep the safety cord wrapped around your wrist.

The reader is referred to *Sound and Vibration** magazine for an up-to-date listing of suppliers of sound level meters (and other kinds of acoustic measurement instrumentation). Each year, *Sound and Vibration* devotes an entire issue to instrumentation; an example is the issue of March 1978.

Considerable nonacoustical data should be obtained to support the noise exposure information. Such data include plant location and product; pertinent personnel and their positions in the organization; persons present during measurements; time span of measurements; room layout and dimensions; sketches of machines; descriptions of machines and operational data (speed, quantity, and size of produced products); the average daily time that machines are in operation or producing noise; worker and measurement locations; and photographs.

Other Means to Determine Noise Exposures

Sound level meters may become difficult to use in situations where the noise environment or worker position is constantly changing or when a long time frame is required to gauge a particular exposure adequately. Other instruments and procedures are available for such situations, although they should be used with discretion.

Dosimeter--

Besides sound level meters, the most widely used instrument for determining a noise exposure is the dosimeter. Dosimeters are considerably simpler to use than SLMs because they automatically compute noise exposures. All dosimeters are portable battery-powered devices, worn by workers being monitored. When they are

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activated, they read and store the integrated value of all the partial noise dose exposures. At the end of a time period, the devices are deactivated, and the readouts are used as a basis for determining compliance.

Although dosimeters appear attractive because of their inherent simplicity, they have some drawbacks. At the time of publication of this *Manual*, there is no completed national standard covering the performance of dosimeters. Recent studies suggest the dosimeter buyer can expect performance more or less in proportion to the price of the individual units. NIOSH has published a document concerning the performance of several dosimeters and how they were tested.* Be aware that there may be substantial differences (enough to affect determination of whether a situation is in compliance) in results obtained from using the "best" dosimeter and from using other, more traditional, exposure evaluation techniques. Be aware, too, that by deliberately favoring high or low sound level positions, or by physically tampering with the unit (moving the microphone to inside a pocket, blowing on the microphone, rubbing or tapping the microphone, etc.), a dosimeter wearer can influence the indicated dose upward or downward. Periodic observation of the employee wearing the dosimeter may be needed to attest to the normalcy of the situation being measured.

A different procedure to determine noise exposure makes use of statistical analysis through an instrument called a "sound integrating meter." Special integrating sound level meters are now available to take a microphone signal or tape-recorded signal of an operator's noise exposure and compute statistical measures of the noise, including the noise dose, automatically or semiautomatically.

Once again, the reader is referred to *Sound and Vibration* for a listing of suppliers of dosimeters and other instruments and for more detail on their operation.

How Sure Can I Be of My Evaluation?

If measurement instructions described in the noise regulation and in the literature of manufacturers of noise measuring instruments are followed closely, results should show, with little room for ambiguity, whether a particular situation is in compliance. However, there are limitations on accuracy that may make assessment of the marginal situation particularly difficult. The limitations include:

> Precision of instruments: The best field instruments are designed to read the "true value" to within about 1 dB. Thus, even two of the same model of two properly calibrated Type 1 instruments may yield slightly different readings. Obviously, less precise Type 2 instruments may provide even greater differences.

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*NIOSH Technical Publication No. 78-186. A Report on the Performance of Personal Noise Dosimeters.

- Instrument performance differences: Two different instruments, both meeting laboratory standards for their response, may read field-encountered sounds differently. Thus, depending on microphone directivity and frequency response characteristics and the type of noise signals being analyzed, differences will result. Differences of 1 dB or more are common, and differences of up to about 3 dB are possible, especially for locations having rapidly changing noise conditions or impact-type sounds.

- Representativeness of the exposure: Perhaps this is the most significant factor affecting variation in readings. Daily noise exposure patterns can vary significantly from day to day. This variation would be especially true in job-shop-type operations. There is no simple way to handle this complexity, as the existing OSHA noise regulation makes no provision for variations in daily noise exposure patterns. To meet this problem, you may have to take several repeat observations to determine a realistic range of exposure values.

- Sound levels near 90 dBA: The daily noise dose may be very sensitive to exposures close to 90 dBA. Under current regulations, any sound level below 90 dBA is considered not to contribute to the daily noise dose. What happens if the sound level is constant at exactly 90 dBA? One Type 1 instrument may read that sound level as 89 dBA and another as 91 dBA. As a result, the daily noise dose would approach zero when the lower reading instrument was used and 1.1 when the higher reading instrument was used. A 2- or 3-dB error in instrument precision, even when reading an acceptable 90-dBA noise exposure, could produce a noise dose value of about 1.3 to 1.5. Thus, measurement accuracy and precision are important items in interpreting noise exposures, especially for marginal situations.

Obviously, there are many reasons to be careful in assessing a noise exposure, and these reasons become more critical the closer the situation is to the "just acceptable" or "just unacceptable" noise value.

HOW SEVERE IS THE PROBLEM?

Once a noise problem is identified, its seriousness must be established. In other words, how severe is it? How much noise reduction is needed? Setting an overall noise control goal is useful to establish a framework on which to base all subsequent analysis. Once the objective is established, noise reduction goals can be considered for the individual noise sources that cause the problem. Setting the primary goal also puts the noise problem in perspective, and helps you to choose wisely in selecting noise controls.

Overall Noise Reduction Requirements

In the simplest case, the required noise reduction is found directly by subtracting the desired sound level goal from the existing sound level. The goal may be established by regulation, corporate policy, or ambient conditions.

For example, a noisy operation may be measured at 87 dBA at the property line of a plant. Local noise regulations may limit the plant noise to no greater than the average sound level in the neighboring community. Suitable measurements (perhaps made at a location in every other way similar to the property line position, but far enough from the plant to mitigate the plant's influence on the measurement), indicate the "not-to-exceed" sound level is 71 dBA. In this case, the overall goal would be a noise reduction of 87 dBA minus 71 dBA, or 16 dB.

In an in-plant industrial situation, an individual's noise exposure may be to an essentially continuous sound, as would be the case for a filling machine operator in a bottling plant or a loom operator in a textile plant. Typical sound levels in such environments may be on the order of 100 dBA. In such cases, the noise reduction goal might be 10 dB in order to meet OSHA regulations.

For more complex situations, where the sound level is variable, but always above 90 dBA, a single-number noise reduction objective can still be established by converting the worker's daily noise dose into an "equivalent sound level," or, in other words, by determining what continuous sound level would yield the same daily noise dose as the variable sound. To do so, use the following equation, a combination of Equations 2.2 and 2.3:

$$\text{equivalent } L_A = \frac{\log D}{0.2 \log 2} + 90 \ . \qquad (2.4)$$

For example, if the worker's daily noise dose, D, is 2.0, the equivalent L_A = 95 dBA.

The difference between 90 dBA and the equivalent sound level represents the noise reduction required to bring the situation into compliance in such cases. Therefore, it can be used to establish an overall noise reduction goal.

A variable noise exposure may also reflect the employee's work pattern, which may place him in several different noise environments during the course of a day. He may work for 2 hr in a quiet 72-dBA *environment (1)*, 4 hr in a 95-dBA *environment (2)*, and 2 hr in a 100-dBA *environment (3)*. In this case, he would incur partial noise doses according to *environment (1)*; $\frac{2}{\infty} = 0.0$

environment (2); $\frac{4}{4} = 1.0$

environment (3); $\frac{2}{2} = 1.0$.

This worker's total noise exposure is 2.0, which exceeds the allowable value of unity. In such situations, you can consider several choices for a noise reduction objective. In the illustrated case, there are three ways to bring the noise exposure into compliance: quieting either *environment (2)* or *environment (3)* to below 90 dBA, to eliminate either of the partial doses incurred in those areas, or quieting both *environments (2) and (3)* by amounts suitable to bring the *total* of the partial noise doses incurred down to 1.0 or less.

The goals in this case could become:

- a noise reduction of 6 dB in *environment (2)*, or
- a noise reduction of 11 dB in *environment (3)*, or
- a noise reduction of about 4 dB in *environment (2)*, plus a noise reduction of about 8 dB in *environment (3)*.

In such cases, where there is a variety of goals, you should consider each before choosing a course of action. You will probably decide to analyze the problem further to determine the cause of the various partial noise doses and to determine the possibilities of being able to control the noise from the identified sources.

Frequency-by-Frequency Noise Reduction Requirements

Is it useful to apply a frequency analysis to the measurement of existing noise conditions? Yes. The added detail provided by frequency analysis will help both in qualifying the severity of the problem and in diagnosing where the noise comes from. The usefulness of frequency analysis in evaluating the severity of a noise problem is evident when we can pinpoint the frequencies of a noise for which sound pressure levels are excessive. To do so, we must first express the overall noise objective (e.g., 90 dBA) on a frequency basis.

In effect, there are a large number of frequency spectra that will produce a particular sound level. ("Frequency spectra" refers to distribution of a complex sound, whether expressed in octave-band sound pressure levels or in some other, narrower, bandwidth evaluation of the total noise.) Figure 2.5 shows a particular spectrum

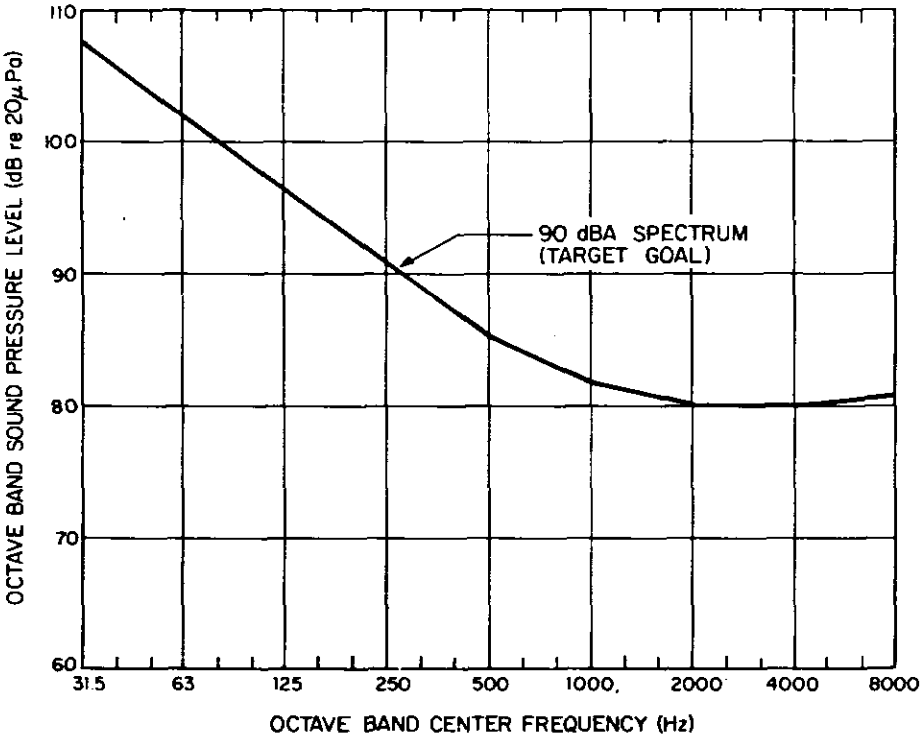

Figure 2.5. Recommended frequency spectrum for OSHA noise problems.

often used for OSHA noise problems. This spectrum has been developed from prior studies of the relation between amplitude and frequency characteristics of industrial noise and exposure time to the hearing damage risk of workers. This spectrum could serve as a target goal for reaching a 90-dBA sound level.

How is this spectrum applied? This is the procedure: Measure the frequency distribution (in octave bands) of the sounds at an operator location and plot the octave-band values on a graph already containing the preselected 90-dBA spectrum. Figure 2.6 shows such a plot of a problem noise with a sound level of 94 dBA. Note that the 90-dBA target goal is exceeded only in the 2000-, 4000-, and 8000-Hz octave bands. If you were to reduce the sound pressure levels in those three octave bands by the respective algebraic difference between the levels in the problem noise and in the 90-dBA spectrum, you would be assured of reducing the problem noise to 90 dBA or below.

Note the advantage to this approach. You have isolated the noise problem to a part of the overall noise — the higher frequency noise. There is no need to consider the low-frequency noise and, thus, you can concentrate further efforts (if needed) on dealing with the high-frequency noise.

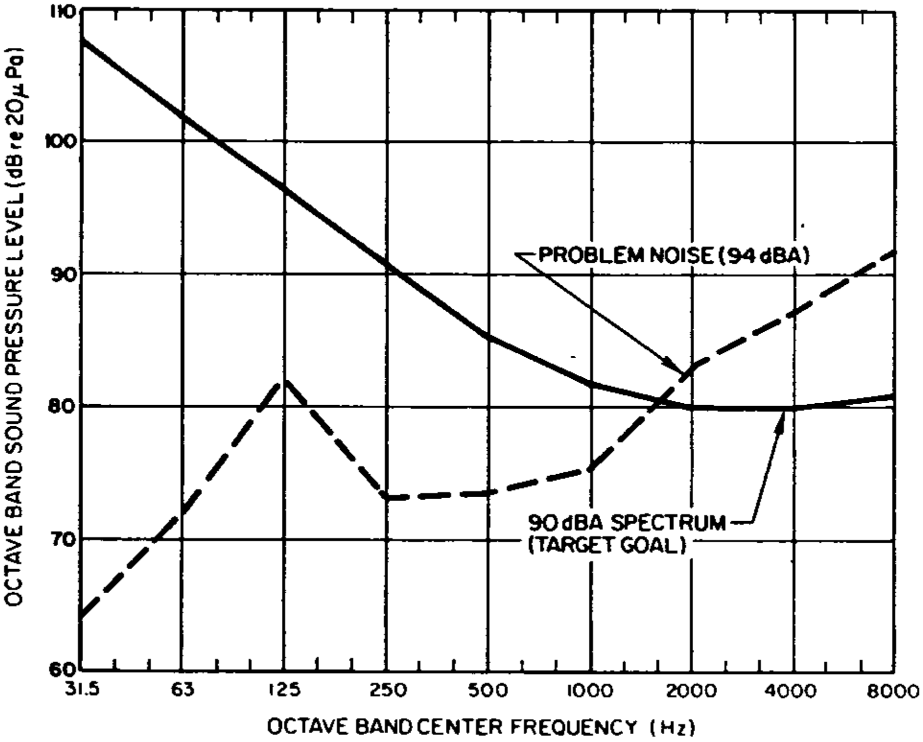

Figure 2.6. Determination of required noise reduction.

But why bother to concentrate on an isolated frequency band? You could have reduced the 94-dBA sound to 90 dBA by reducing each octave band by only 4 dB, as opposed to greater dB reductions indicated by the target goal approach. Would it not be easier to try for a 4-dB across-the-board reduction? The answer is generally no. Almost invariably, it is easier and cheaper to obtain noise reduction in the higher octave bands.

Note further that you would not benefit by finding and treating solely those noise sources responsible for the low-frequency components of the problem noises. The sound level is, in fact, dominated by contributions from the higher octave bands and would remain high, no matter what is done to the low-frequency sounds. The 90-dBA spectrum illustrated in Figures 2.5 and 2.6 automatically pinpoints those problem frequencies that contribute most to the sound level; they are, therefore, those that most merit noise control.

NOISE SOURCE DIAGNOSIS

Up to this point, the discussion on noise problem analysis has concentrated on defining overall goals. Now we start to consider more specific objectives, such as how much noise reduction is appropriate for a particular machine, machine component, or process. This aspect of noise problem analysis is closely related to identifying where the noise is coming from: the topic of noise problem diagnosis. To perform even a simple noise problem diagnosis, you must be able to add decibels.

Decibel Addition

The calculation involved in decibel addition is fundamental to noise control engineering. Suppose we know the sound levels of two separate sources, and we want to know their total when the two sources are operating simultaneously. We make the basic assumption that the noises are random and that they bear no relationship to each other (that is, they do not have the same strong pure tones). The formula for calculating the combined level, L_c, of two individual decibel levels L_1 and L_2, is

$$L_c = L_1 + 10 \log [10^{(L_2 - L_1)/10} + 1]. \qquad (2.5)$$

As a practical example, you might have already measured or obtained (at a specified distance or location) the sound levels of two individual sound sources, each operating alone, and you now want to know the sound level (at the same distance) of the two together. For random sounds, the total measured on an SLM would agree (within measurement accuracies of about 1 dB) with the calculated total, using Equation 2.5. Figure 2.7 or Table 2.3 simplifies decibel addition without the formula.

An alternative form of decibel addition, which relies on a few simple rules which can be learned (results accurate to ±1 dB) is:

(1) When two decibel levels are equal or within 1 dB of each other, their sum is 3 dB higher than the higher individual level. For example, 89 dBA + 89 dBA = 92 dBA, 72 dB + 73 dB = 76 dB.

(2) When two decibel levels are 2 or 3 dB apart, their sum is 2 dB higher than the higher individual level. For example, 87 dBA + 89 dBA = 91 dBA, 76 dBA + 79 dBA = 81 dBA.

(3) When two decibel levels are 4 to 9 dB apart, their sum is 1 dB higher than the higher individual level. For example, 82 dBA + 86 dBA = 87 dBA, 32 dB + 40 dB = 41 dB.

(4) When two decibel levels are 10 or more dB apart, their sum is the same as the higher individual level. For example, 82 dB + 92 dB = 92 dB.

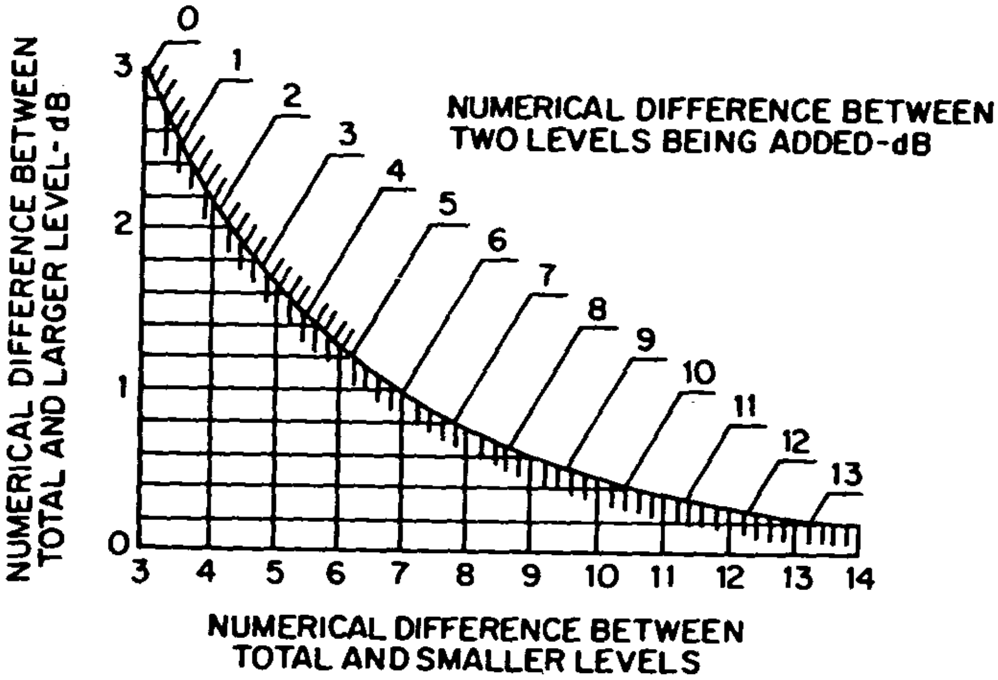

Figure 2.7. Chart for combining decibel levels*.

Table 2.3. Table for obtaining decibel sum of two decibel levels.

DIFFERENCE BETWEEN TWO DECIBEL LEVELS TO BE ADDED (dB)	AMOUNT TO BE ADDED TO LARGER LEVEL TO OBTAIN DECIBEL SUM (dB)
0	3.0
1	2.6
2	2.1
3	1.8
4	1.4
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4
11	0.3
12	0.2

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*From Handbook of Noise Measurement. 7th ed., A.P.G. Peterson and E.E. Gross, Jr. GenRad, Inc., Concord, MA 01742. This chart is based on one developed by R. Musa. Reprinted by permission of the publisher.

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As a practical example, you might have already measured or obtained (at a specified distance or location) the sound levels of two individual sound sources, each operating alone, and you now want to know the sound level (at the same distance) of the two together. For random sounds, the total measured on an SLM would agree (within measurement accuracies of about 1 dB) with the calculated total, using Equation 2.5. Figure 2.7 or Table 2.3 simplifies decibel addition without the formula.

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