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Electric Power Application and Installation Guide

Noise

LEBX0031

WHERE THE WORLD TURNS FOR POWER

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Definitions

Noise can be defined as all unwanted sounds. Music is sound and can be pleasant to some people and noise to others. Noise and sound are often used to describe the same physical characteristics. Noise is generally random in nature without distinct frequency components. Noise can produce undesirable psychological effects on people and physical damage to the ears. Noise can be annoying to affect verbal communications at work and away. At times, it may impact behavior, including short term and long term hearing loss, muscle tension, respiratory reflexes, stress level, heart function, etc. Recognizing this, many governmental agencies around the world have established regulatory limits for various levels of noise.

The noise from the engine comes mainly from combustion, mechanical, for the exhaust and air intake sources.

Frequency of sound refers to the rapidity or cycles of an oscillation in a unit time. The conventional unit is Hertz (Hz) — one Hz being one cycle per second.

Sound Waves and Measurement

As sound waves radiate, their strength diminishes (see Table 1). As distance traveled doubles, the wave amplitude is reduced by one-half. This rule applies if the first measuring point is at least two or three times the largest dimension of the noise source, usually about three feet.

Distance	Sound Strength
X	100%
2X	50%
4X	25%

Table 1. Distance vs. wave amplitude.

Sound waves impinging on a microphone produce voltages proportional to sound pressures. The signals measure amplitude or strength, of the *sound pressure* waves. Amplitude and frequency are the only sound properties measurable using ordinary techniques.

Sound Pressure

The extensive audible range of sound complicates noise ratings. The human ear hears pressure levels that are about 100,000 times stronger than the lowest pressure it is affected by. For this reason, measuring instruments have extraordinary range and are scaled in decibels (dB). The decibel scale is logarithmic, which allows the wide range of sound pressures to be measured in only two- or three-digit numbers.

Sound Pressure Level (SPL) in dB =

$$20 \log_{10} \times \frac{\text{Measured pressure}}{\text{Reference pressure}}$$

The reference pressure is taken as: 20 μPa or 2×10^{-4} microbars = 0 dB. The relationship between μPa and dB is that when multiplying the sound pressure (μPa) by 10, 20 dB is added to the dB level. Decibel (dB), is the relative measurement of amplitude of sound. Sound is a pressure which makes the membrane in the human ear deflect. The softest pressure the human ear can hear is 20 μPa (1 atmospheric pressure = 1 bar = 100 kPa = 14.5 psi) but the ear can take pressures up to more than 1 million times higher.

Frequency — Weighting Networks

The ear is more sensitive to high frequencies than low frequencies. To approximate the effect of sound on the average person, measurements are weighted according to frequencies corresponding to the sensitivity of the ear. Loudness can be measured by filtering the microphone signal to reduce the strength of the low frequency signals and give more weight to frequencies in the 5,000-10,000 Hz range. The signal from the measuring microphone is fed to an amplifier, then to an attenuator, which is calibrated in decibels. The signal is then fed to one of four weighting networks, referred to as A, B, C, and D. The response of the network chosen modifies the input signal accordingly.

The most commonly used network is weighting A (A-scale), and it is known as dBA or dB(A).

Figure 1 shows the response characteristics for an "A" filter. The result of adjustments throughout the frequency range is a total decibel rating with a correction for various frequencies to approximate ear's sensitivity.

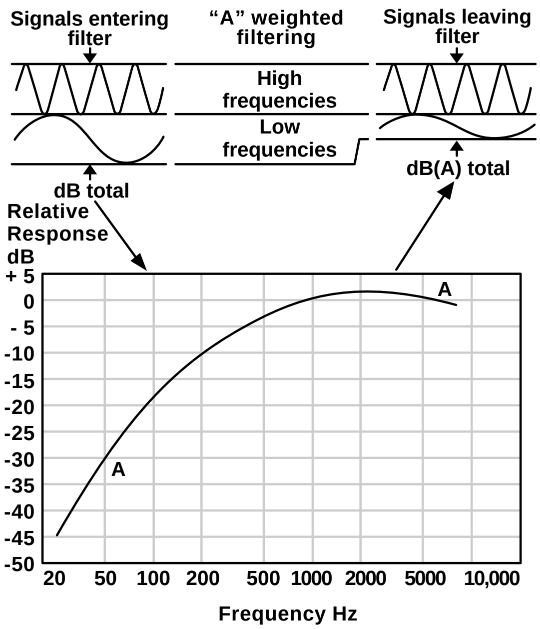

Figure 1. Response characteristics of "A" filter.

Octave Band Levels

More detail is required of the frequency distribution of a noise than provided by an A-weighted measurement. Measurements are made with filters subdividing sounds over the entire audible range into standardized frequency bands, permitting the pressure levels of only the sound within each subdivision to be measured. Each filter spans an octave; that is, the upper frequency limit is twice the lower limit as shown in Figure 2. Sound levels in each octave are measured in decibels and are referred to as octave band levels.

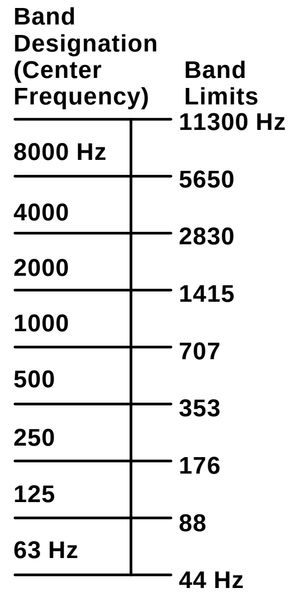

Figure 2. Standard octave bands (ANSI Standard S1.11 IEC 225).

Loudness

The human ear does not use sound pressure decibels to judge loudness. Rating noise loudness is a complex operation because human hearing is also frequency sensitive.

Sounds with frequencies in the 5,000-10,000 Hz range are the easiest to hear; sounds with very low frequencies are the hardest. Hearing loss from exposure to noise is frequency sensitive.

Direction of Sound

Sound is mostly directional, meaning that the sound tends to move more in one direction than another.

The contour of the sound wave can be complex. By measuring the sound pressure level three dimensionally around the engine, the contour can be determined (see Figure 3).

It is not only the source of the sound which will give the direction, but also any kind of reflective surface in the area of the engine, i.e. floor, walls or ceiling.

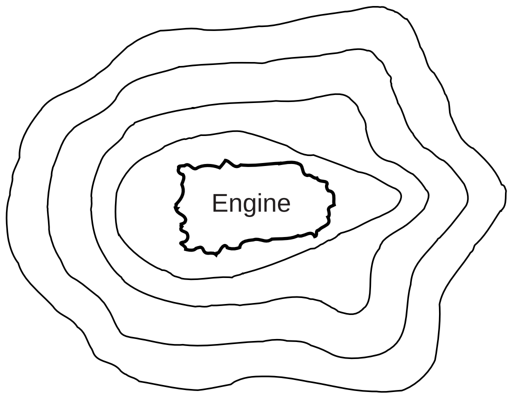

Figure 3. Contour of a sound wave.

Noise Addition

When standing by an engine, the noise heard from other engines operating in the same area will depend on the spacing of the engines and where the person is in relation to the spacing.

A chart showing the combined effect of up to ten equal sound sources is shown in Figure 4.

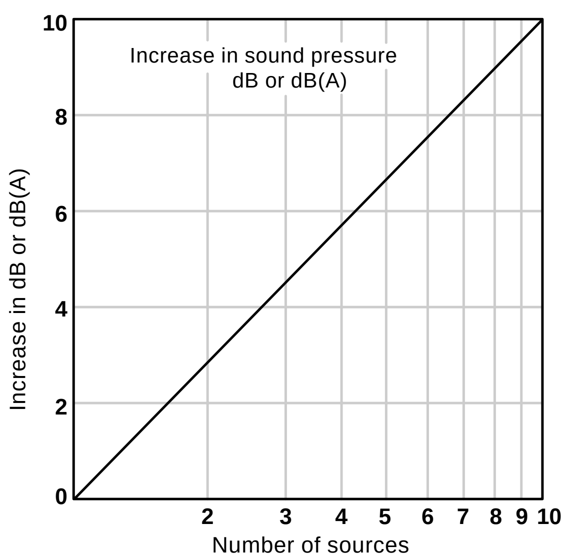

Figure 4. Addition of equal sounds.

Figure 5 shows the versatility of the decibel system. Although calculations are made on the basis of sound power, the system uses measured or calculated sound pressures. Use the difference in the pressure levels of two sounds to find how their combined level exceeds the higher of the two. First adjust the levels for the distances from the source to the spot where the noises are being added. To add a third level, use the same process to combine it with the total of the first two.

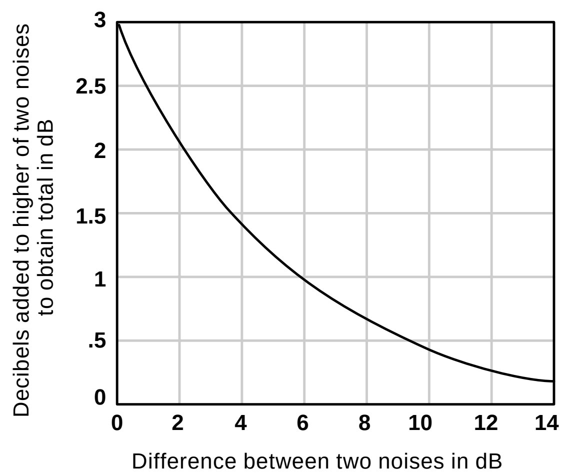

Figure 5. Addition of unequal sounds.

Sound Level Conversions

Sound level information is presented both in terms of sound power level, SWL, dB(A), and sound pressure level, SPL, dB(A). SWL is the total sound power being radiated from a source and its magnitude is independent of the distance from the source. Relative loudness comparison between engines is simply a comparison of their sound power levels at equivalent operating conditions.

When the sound power level (SWL) is known, the sound pressure level (SPL) at any distance from a point source (such as exhaust noise) can be calculated.

The equation for determining the sound pressure level of exhaust noise without any correction for ambient temperature and pressure, is:

Sound Pressure Level, SPL dB(A) =
Sound Power Level, SWL dB(A) - 10 x $\text{Log}_{10}(C\pi D^2)$

Where C = 2 For exhaust source adjacent to a flat surface, such as a horizontal exhaust pipe adjacent to a flat roof.

or C = 4 For exhaust source some distance from surrounding surfaces, such as a vertical exhaust stack some distance above roof.

D = Distance from exhaust noise source (m).

For C = 4 = SPL = SWL - 20 Log_{10} D - 10.99

SPL measurement requires only a simple sound level meter. However, this being the sum of sound waves arriving from every direction, depends on the acoustic characteristics of the environment and varies with position relative to the noise source. SPL cannot be used to describe the strength of a noise source without specifying relative position and room acoustic properties of the test environment. A disadvantage is that sound pressure level conversion is valid for a point source only. It cannot be used for mechanical noise since the source (overall engine) is quite large.

If the sound pressure level of a point source at some distance is known, the sound pressure level at another distance can be calculated using this formula:

$$SPL_2 = SPL_1 - 20 \times \text{Log}_{10} (D_2 \div D_1)$$

Where: SPL_1 = known sound pressure level, dB(A)
SPL_2 = desired sound pressure level, dB(A)
D_1 = known distance, m (ft)
D_2 = desired distance, m (ft)

Noise Exposure

As mentioned before, exposure to excessive noise causes permanent hearing damage and adversely affects working efficiency and comfort. Recognizing this, the U.S. Government created the Occupational Safety and Health Act (OSHA) which established limits for industrial environments.

When an individual's daily noise exposure, designated D(8), is composed of two or more periods of noise at different levels, the combined effect is calculated by: D(8) = (C1/T1) + (C2/T2) + ... + (Cn/Tn). Where Cn is duration of exposure at a specified sound level and Tn is total time of exposure permitted at a specified sound level (see Table 2). The noise exposure is acceptable when D(8) is equal to or less than 1.

Duration of Daily Exposure (hours)	**Allowable Level** dB(A)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25	115

Table 2. Permissible noise exposures.

TMI Data

TMI contains the specific noise values (SPL) for the specific engine at different ratings. Various definitions are used and most can be found under "HELP" in TMI.

Free Field

Free field means that it is a 100% open area without any kind of sound reflections or other modifying factors.

Sound Pressure Level, SPL, — Mechanical or Exhaust

Sound pressure level is presented under two index headings: mechanical or exhaust.

Over one thousand data points per engine are used to prepare this data. There are eight octave bands and one overall reading taken at four engine speeds, four loads, three distances, and four positions around the engine.

Mechanical

Sound pressure level data is obtained by operating the engine in an open "free" field and recording sound pressure levels at a given distance. The data is recorded with the exhaust sound source isolated.

Exhaust

Sound pressure level data is recorded with the mechanical sound source isolated.

Measurements

The instrumentation used are Larsen/Davis and Hewlett-Packard. All measurements are for "without" radiator fan arrangements.

Tolerances for the overall and for the octave band data is shown below:

Overall	Plus or minus 2 dB(A)
60 Hz	Plus or minus 5 dB(A)
125 Hz	Plus or minus 5 dB(A)
250 Hz	Plus or minus 4 dB(A)
500 Hz	Plus or minus 3 dB(A)
1000 Hz	Plus or minus 2 dB(A)
2000 Hz	Plus or minus 2 dB(A)
4000 Hz	Plus or minus 2 dB(A)
8000 Hz	Plus or minus 2 dB(A)

The confidence level of the above data is 99.73%, which means that only 27 out of each 10,000 engines measured of the same configuration as listed could fall outside of the nominal values plus the tolerances shown for the same engine, the repeatability tolerance is ±1 dB(A).

Engine Installations

Engine packages include an engine and some piece of driven equipment, such as a generator or a compressor. Guidelines for installation design are provided, along with information on using noise data on Caterpillar units from TMI.

Some installations require very little noise abatement (for example, a remote facility far from people). Very sensitive installations, on the other hand, may require extensive noise abatement measures. Because of the variety of noise criteria that may apply to a given site, it is impossible to provide a description of abatement measures meeting all site criteria. It is the responsibility of the facility designer to ensure that the specific criteria of the site are met.

It is strongly advised that a noise control expert be involved in the facility design process from the beginning if the engine unit is to be installed in a building or area that is noise sensitive. Since internal combustion engines produce high noise levels at low frequencies, many traditional noise control approaches are relatively ineffective. Every aspect of facility design must therefore be reviewed with special emphasis on low-frequency attenuation characteristics in order to meet site criteria.

A typical approach to designing an engine installation is as follows:

- *Recognize the special requirements of engine installations.* The first step is to become aware of the special noise characteristics of engine installations. Possible sources, paths, and receivers of large-engine noise are reviewed.

- *Identify site noise criteria.* For example, is the installation in a remote or a populated area? Is it within a building sensitive to noise (for example, a laboratory or a hospital)? What regulations, standards, or restrictions apply to noise? The noise criteria form an essential part of the design goals. Since criteria vary from site to site, this guide cannot identify all the criteria that apply to a particular site. However, some guidelines for site noise criteria are provided.

- *Identify and select appropriate noise abatement measures.* Guidelines for attenuation of noise, both through commercially available equipment and through facility construction, are provided.

Noise Control

Noise can be either airborne or structure-borne transmitted. Airborne noise is transmitted through air. Structure-borne noise is vibration transmitted through a structure; typically supporting the engine. Noise control methods are different for the two sources. Noise control refers to appropriate technology used for noise attenuation to acceptable levels.

Noise criteria at various frequencies for typical areas are shown in Table 3.

Airborne Noise Control

Airborne noise control is a straightforward and well-developed area compared with structure-borne noise control. There is abundant information available on sound absorption and transmission properties of common construction materials, and there are accepted and proven procedures for applying that information.

However, it is important to recognize that much of the conventional information and procedures were developed for higher-frequency noise, and thus may not be appropriate for engine units, which produce strong low-frequency acoustic energy. For example, structural and acoustic resonances (conditions of minimum dynamic stiffness) may coincide with pure-tone frequency components of the engine noise, resulting in very efficient transfer of energy. Conventional building acoustics generally is based on statistical descriptions of noise, and therefore does not address resonance effects.

For some installations, airborne noise must be controlled at several receiver points: inside the engine room; in other rooms in the building; and outside the building. The simplest way to reduce airborne noise within a building is through good building layout. Equipment rooms should be situated far from sensitive receiver locations in the building. This takes advantage of the fact that propagating sound energy diminishes with distance from the source. In addition, there are two other methods of controlling airborne noise: with high transmission loss walls and with absorption.

It is helpful to review some terminology before discussing the sound transmission characteristics of walls. The transmission loss (TL) of a partition is a measure of the ratio of energy incident on the wall to that transmitted through the wall, expressed in dB. The less relative sound transmitted through the wall, the higher the TL of the wall. TL is a function of frequency.

The sound transmission class (STC) of a partition is a single-number rating calculated from the partition TL. A reference contour is adjusted against the measured TL data, and the STC rating equals the value of the adjusted contour at 500 Hz. The STC rating does not include information in frequency bands below 125 Hz. This rating is useful for designing walls that provide insulation against the sounds of speech and music; it is inappropriate for industrial machinery with low-frequency energy such as engine units. TL data should be used instead, whenever possible.

Octave Bands in Cycles Per Second	31.5	63	125	250	500	1000	2000	4000	8000
Highly Critical Hospital or Residential Zone	71	63	44	37	35	34	33	33	33
Night, Residential	73	69	52	44	39	38	38	38	38
Day, Residential	76	71	59	50	44	43	43	43	43
Commercial	81	75	65	58	54	50	47	44	43
Industrial-Commercial	81	77	71	64	60	58	56	55	54
Industrial	87	85	81	75	71	70	68	66	66
Ear Damage Risk	112	108	100	95	94	94	94	94	94

Table 3. Noise criteria.

In typical partitions, sounds at higher frequencies are attenuated more than sounds at lower frequencies. The highest transmission loss values are found in cavity wall (two-leaf) constructions, where the two separate wall layers are well isolated. The transmission loss values increase with the masses of the individual leafs, the depth of the airspace, and the characteristics of any sound-absorptive material in the airspace.

It should be noted that noise leaks can severely degrade the performance of a partition. Materials are tested for their transmission loss characteristics in a controlled laboratory setting, with all edges sealed. But in typical construction, sound leaks may occur at the edges of the wall, at openings for pipes or electrical outlets, and across shared ceilings (so-called flanking paths). A wall with a leakage area equal to 0.01% of that of the wall area cannot exceed STC = 40, no matter how high the STC of the wall construction.

A partition may include elements with various transmission loss characteristics, for example, windows and doors. The transmission loss of the partition must be calculated taking all elements into consideration.

To estimate the total airborne noise transmission loss of a facility, subtract the noise value for each receiver from the estimated room-average sound pressure level. If there is more than one space, the sum of the individual contributions must not exceed the criterion.

Mechanical Noise

Many techniques for isolating generator set vibrations are applicable to mechanical noise isolation. Modest noise reductions result from attention to noise sources, i.e., reducing fan speeds, coating casting areas, and ducting air flows. But for attenuation over 10 dB(A), units must be totally isolated. One effective method utilizes concrete blocks filled with sand to house the generator set. In addition, the unit must incorporate vibration isolation techniques. A rough guide comparing various isolation methods is illustrated in Figure 6.

Completely enclosed engines are impractical due to openings required for pipes, ducts, and ventilation. Enclosures with numerous openings rarely attain over 20 dB(A) attenuation.

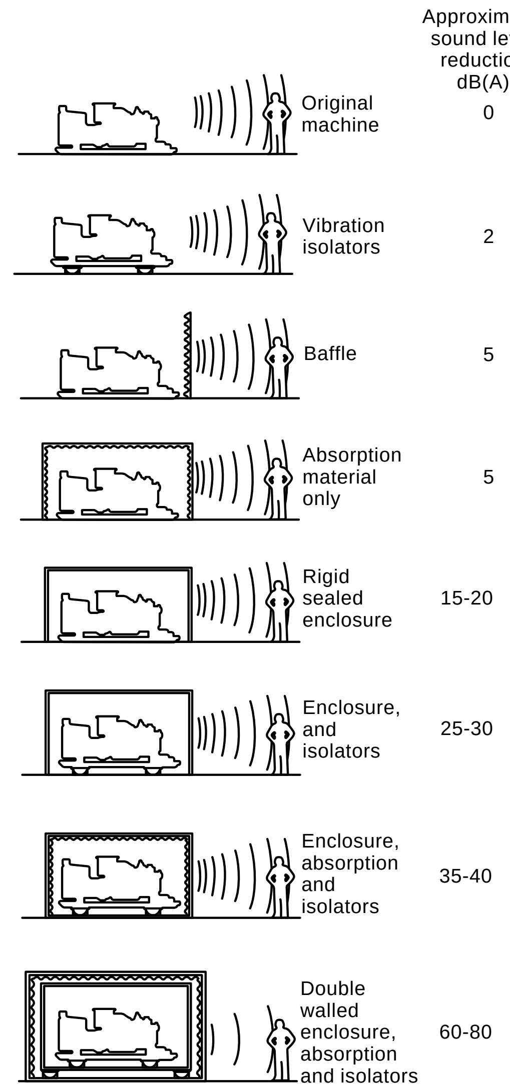

Figure 6. Illustration of isolation methods.

Intake Noise

Intake noise attenuation is achieved through either air cleaner elements or intake silencers. Noise attenuation due to various air cleaners and silencers can be supplied by the component manufacturer.

Exhaust Noise

Exhaust noise is typically airborne. Exhaust noise attenuation is commonly achieved with a silencer typically capable of reducing exhaust noise 15 dB(A) when measured 3.3 m (10 ft) perpendicular to the exhaust outlet. Locating it near the engine minimizes transmission of sound to the exhaust piping. Since the number of cylinders and engine speeds result in varied exhaust frequencies, specific effects of mufflers must be predicted by the muffler manufacturer.

Silencers/Mufflers

Silencers are used to attenuate airborne noise in piping and duct systems. Their effectiveness generally is frequency sensitive, so it is essential that they be matched to the frequency content of the noise. There are two major categories of silencers; dissipative and reactive. Dissipative silencers use absorptive, fibrous material to dissipate energy as heat. They are effective only for high frequency applications (i.e., 500 to 8000 Hz).

Reactive silencers, on the other hand, use a change in cross-sectional area to reflect noise back to the source. They are typically used for low-frequency applications (such as internal combustion engines), and they may incorporate perforated tubes to increase broadband performance. The effectiveness of a reactive silencer depends on its diameter, volume, and overall design. Multi-chamber silencers provide maximum sound attenuation with some flow restriction. Straight-through silencers offer negligible flow restriction with slightly lower sound attenuation.

Stack silencers are designed to be inserted directly into a stack and withstand a harsh environment. Finally, some manufacturers offer combination heat-recovery silencers for hot gas exhaust.

Most manufacturers offer silencer dynamic insertion loss (DIL) information in octave bands from 63 to 8000 Hz, tested in accordance with ASTM E-477. DIL is the difference in sound level with and without a silencer installed in pipe or duct with air flow. Some manufacturers rate silencers as being “industrial”, “commercial”, or “residential” grade; in such a case, the DIL of the silencer should still be requested in order to determine the grade of silencer most suitable for the installation.

To determine the DIL required by a particular application, information is required on the actual (unsilenced) and desired noise levels at the emission point. The difference between these values is the silencer DIL. The desired source level is determined from the criteria governing the site.

When used to attenuate exhaust noise, the silencer must be sized to accommodate the specified volume of flow without imposing excessive backpressure. The flow area for a given backpressure can be calculated from the engine exhaust flow (CFM) and the exhaust temperature. The pressure drop will determine the required size of the silencer.

Sound Absorption Treatments

Acoustically absorptive surfaces convert acoustic energy into heat, and are generally described by sound absorption coefficients in octave bands. Absorptive surfaces may be used to reduce the reverberant (reflected) sound field within a room. As mentioned above, reducing the reverberant field within a room can also reduce the noise field outside the room. It should be noted that absorptive materials do not attenuate the direct sound field.

The absorption of a room may be estimated on an octave-band basis from the absorption coefficients and the area of each room surface (ceiling, walls, and floor). Alternatively, the room absorption may be determined through reverberation time measurements. Using this information and the source sound power data, the noise reduction that can be obtained by adding absorption to a room may be determined. Information on the absorption coefficients of a material or element may be obtained from the manufacturer.

A wide variety of commercially available sound absorbing elements are available for almost every application. Ceiling treatments include lay-in tiles or boards (for suspended ceilings), tiles that can be directly affixed to the ceiling surface, and suspended absorbers.

Acoustic wall panels range from "architectural" panels with attractive finishes to perforated metal panels filled with absorbing materials. Concrete blocks with slotted faces and acoustical fill may be used to add sound absorption to normal concrete block wall construction.

Sound absorbing elements are selected on the basis of their sound absorption coefficient in the octave bands of interest. In addition, the elements must survive their environment, be easy to maintain, and offer acceptable flame spread properties.

Enclosures and Barriers

Enclosures and barriers block and reflect direct-radiated sound from a noise source. A barrier provides a "shadow zone" of sound attenuation between the source and the receiver, much as light casts a shadow behind a wall. Full enclosures may be used around the source or around the receiver (e.g., personnel in affected areas). Partial barriers may be used to protect noise sensitive areas, by locating receivers in the shadow zone.

The effectiveness of a barrier in blocking noise transmitted through it is a function of its sound transmission characteristics. Both enclosures and barriers should be lined with absorptive material to be fully effective. In the case of an enclosure without absorption, the reverberant field inside the enclosure can greatly increase the interior sound pressure, so that noise outside the enclosure is also increased. In the case of a barrier without absorption, the noise is simply reflected elsewhere. Transmission loss and absorption are the main selection criteria for barriers and enclosures, and each is a function of frequency.

Opening in enclosures should be acoustically treated, for maximum effectiveness. Also, when using sound barriers it is important to control "flanking path" (sound paths around the barrier).

There are many types of commercially available enclosures and barriers. Complete enclosures for specific types of mechanical equipment are available, some of which include silenced air inlets/exits and a reactive silencer for exhaust noise. Several types of modular panels are available that may include sound absorbing material on one or both sides of the panel. Outdoor barriers, designed to resist wind and seismic forces, are also available to block or reflect noise outdoors.

Along with acoustical performance, practical issues must be considered in using barriers or enclosures. Engine enclosures require ventilation to dissipate the heat that builds up within the enclosure. The enclosure must be accessible for maintenance and inspection, and may require panic latches on doors. Acoustic materials within the enclosure must be fire-resistant.

Structure-borne Noise Control

The purpose of a vibration isolation system (whether simple or compound), or a wave barrier, is to control the transmission of structure-borne noise from the engine unit to the building structure, either directly or through the ground.

Those measures are intended to control noise close to the source, where control measures generally are most effective. However, even with effective isolation mounting of the engine unit it still may be necessary to provide additional structure-borne noise attenuation in the building construction. The simplest way to attenuate structure-borne noise along a path (at least conceptually) is to increase the distance between the source and receiver, since the amplitude of structure-borne noise decreases with increasing distance from the vibration source. The attenuation of noise in concrete-frame buildings has been found to be about 5 dB per floor for frequencies up to 1000 Hz. Attenuation for vibrations traveling along continuous concrete floor slabs typically range from 1.5 to 2 dB/meter. In general, there is less attenuation along horizontal building structures.

Another way to attenuate structure-borne noise is through structural discontinuities. A discontinuity, or impedance mismatch, causes a reflection of energy back toward the source, thereby controlling noise transmission. Such discontinuities are usually filled with a resilient material to prevent debris falling into and "shorting out" the gap. Semirigid fiberglass board is normally used to fill wall gaps, while asphalt-impregnated fiberglass board is normally used between on-grade slabs, foundations, and footings. Many times, large buildings already incorporate expansion joints to allow for thermal expansion and contraction. These may be used to attenuate structure-borne noise by placing the source and receivers on opposite sides of the expansion joint. It is essential that construction elements, pipes, or any other rigid connections do not bridge these discontinuities.

In addition to the source and the path, receiver locations can also be treated to control structure-borne noise in some situations. For example, a "floating floor" construction may be used to isolate the receiver (e.g., a person or some piece of vibration-sensitive equipment) from building vibration.

Foundation

Foundation Design is a very important and often overlooked aspect of large-engine unit facility design. Large-engine units, as noted above, emit relatively strong low frequency energy — structure-borne as well as airborne. If the facility design does not account for both forms of noise, it is likely that site noise criteria will not be met. (Foundation design for installations where noise is not an issue is discussed in the Mounting section.)

Unfortunately, structure-borne transmission and radiation is much more difficult to analyze than airborne noise. Whereas it may be relatively straightforward to estimate the airborne noise transmission loss of the building structure and various types of noise control systems, and thereby assess the adequacy of a facility design, reliable quantitative estimates of structure-borne noise transmission may be extremely difficult or impossible to obtain with current technology, particularly at low frequencies. Thus, the usual approach for noise-sensitive installations is to over-design for structure-borne noise, to ensure that it is not a problem. This means taking care to control every possible structure-borne noise path. Especially in this area, designers are strongly urged to consult qualified professional noise control engineers for noise-sensitive installations.

Engine units usually are mounted on concrete pad or metal deck foundations, using the spring mounts between the unit base and the foundation. Some of the smaller engine units come with isolators between the engine/ generator and base and do not require additional spring mounts for the unit base. Since the unit base provides sufficient stiffness for alignment and relative deflection of the engine and the driven equipment, there is no need to rely on the foundation for additional stiffness. Thus a foundation that is adequate for supporting the static load of the unit will be satisfactory for many installations where noise is not a critical concern.

In installations where noise is a major concern, attention must be directed toward all elements of the isolation system and to the structural paths between the foundation and the rest of the building structure. Adequate isolation often can be achieved with a simple system, but some installations may require a compound isolation system.

Notes

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