TURBOMACHINERY NOISE RATING

by

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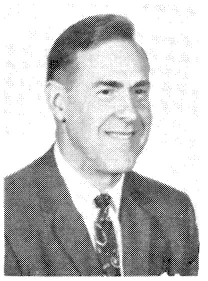

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ABSTRACT

An expression of the noise rating of a machine is an important part of its performance specification. Precautions should be taken, however, to make sure that the noise emission specification keeps the true objective in mind, and is neither too stringent nor too lenient.

It is a costly mistake to demand more detailed information and more noise reduction than is necessary, but the reverse is also true. Therefore it is important to know when to require octave band or third octave band data, instead of overall A-Weighted levels, and when to request a firm sound guarantee instead of estimated noise emission levels.

The intended use of the noise rating information should determine whether sound pressure levels are needed, or whether extra effort is justified to obtain sound power levels. Because of the increased emphasis on sound power ratings, the "two-surface method" deserves consideration as the best technique to use in industrial environments. An Appendix is provided for the reader who may not be familiar with the definitions of all the terms.

If you were going to purchase a large centrifugal compressor or pump, would you rather have a quiet one or a noisy one? The answer to this question is obvious to both machinery manufacturers and purchasers, and consequently a statement of maximum acceptable noise emission is included in practically all machinery performance specifications.

The answers to several other pertinent questions are not quite as obvious. Some sound specifications are copied, word for word, from other sound specifications. Technical errors that appear in one, appear in the others, and it seems in some cases that the objectives of the specifications, and the consequences of enforcing them, in the way they have been written, have not been clearly thought out. This applies to both manufacturers and purchasers alike.

For example, one product noise specification set 80dBA as the maximum permissible noise level. When asked why 80dBA was necessary, the reply confirmed that 90dBA was really what was required. But because of possible manufacturing and measurement tolerances it was decided to set 85dBA as the goal, and then a 5dBA factor of safety was included, making the specification level 80dBA. This could make a tremendous difference in cost, as well as how the sound control is accomplished.

It seems appropriate, therefore, to examine some of the factors involved in setting acoustic design goals, in manufacturing quiet machinery, in testing it to confirm compliance with the specification, and in expressing the actual noise rating. Noise control objectives, and economic consequences should be understood. Federal, State, and local noise control legislation, some already enacted, and others imminent, make this analysis not only desirable, but extremely important.

Relative costs and values must be assessed

1. What percentage increase in price would you be willing to pay for a quiet design offering a noise reduction of, say, 15dBA?
2. Would you pay more for 15dBA reduction by internal design changes than you would for 15dBA by an external acoustic enclosure? How much more?
3. Would you be willing to accept a decrease in operating efficiency to obtain a quieter design using no enclosure or lagging?
4. Would you pay more for a firm sound guarantee than for simply an estimate of the noise?
5. Would you pay more for a sound guarantee in terms of octave band levels than you would for one in terms of overall dBA? Would you pay still more for ⅓ octave-band data?
6. Would you pay more to get sound power levels than to get sound pressure levels?
7. What accuracy would you expect if you wanted to measure the noise after the machine had been installed on your property, to verify the guarantee?
8. Would you be willing to pay a higher price for a noise emission guarantee stating octave band levels accurate to plus or minus 2 decibels than you would for accuracy of plus or minus 5 decibels?

Noise reduction is costly

Anyone who has worked on machinery noise reduction knows that in many cases it is fairly easy to get several decibels reduction with very little effort, simply by locating and identifying the major noise source and making a rather obvious improvement.

The next few decibels are more difficult to obtain. More looking, more identification, more recording, and narrower-band analyses are necessary.

After this the going gets really rough. Many noise sources all seem to have the same sound level, and reducing one, or several of them, has no effect on the overall noise, because they combine logarithmically, and all of them must be reduced before the overall level is improved. This is why the costs of noise reduction increase exponentially as the acoustic goal gets lower and lower.

It is a mistake to demand more sound control than you actually require. The trick is to know what you really need. Unknown future permissible sound levels in the Occupational Safety and Health Standard; unknown product noise emission levels to be established by the Environmental Protection Agency; and not knowing whether Federal Standards will preempt state and local regulations cause purchasers to anticipate lower and lower permissible levels and thereby write more stringent machinery sound specifications than they would otherwise. This increases costs.

Noise control by design not necessarily best

Everyone agrees that it is better to design quiet machinery than to rely on acoustical enclosures and lagging after the machines have been built. Maintenance is easier, the equipment is accessible for inspection checks and vibration measurements, and heat dissipation problems are minimized. But when large, high speed, high horsepower turbomachinery has been designed, developed, and tuned to maximum efficiency, machinery manufacturers, and purchasers as well, are reluctant to do anything internally that may reduce that efficiency.

Certain design changes, effective in reducing noise, are also accompanied by a sizeable reduction in efficiency. Most purchasers do not want to accept this when they realize that a few points in efficiency of a large machine means greatly increased operating costs for the life of the machine. Their reluctance is justified when it is understood that external sound control usually can reduce the noise to acceptable levels without disturbing the internal design, and in most cases can provide more noise reduction than is attainable by internal design changes alone.

External noise control techniques, such as acoustic enclosures, lagging, mufflers, vibration isolation, and damping, must not be considered as "second class" noise reduction, but as a perfectly acceptable approach.

Noise emission ratings are necessary

The purpose of sound specifications and sound guarantees is to be sure you will not be in violation of some noise emission standard, or some noise immission regulation. Noise emission standards set maximum sound pressure levels or sound power levels with respect to the machine. Noise immission regulations establish permissible sound levels in work locations, on construction sites, or crossing plant boundaries or residential property lines. The OSHA Occupational Noise Exposure Regulation is an example of a noise immission regulation.

If a purchaser is interested only in complying with the OSHA regulation, a statement of overall, A-Weighted sound level in dBA is all that is needed. This is sufficient also if the noise crossing the plant boundary is to be calculated and only one machine is in operation.

If there are a number of machines of different types, and boundary sound levels are to be predicted, octave band data should be available, even if the property line levels are stated in dBA only, because errors may result if sounds are combined on an overall basis.

More instrumentation is needed, and more time is required to obtain octave band data than to read a simple A-Weighted sound level.

Octave-band sound guarantees may be difficult to meet

Problems may arise when a purchaser demands a firm guarantee that octave band levels will not exceed his specification when the machine has been installed on his own property. He may be interested in only dBA, and has written his octave band sound specification so that the octave band levels add up correctly to the overall dBA he wants; but now the guarantee becomes much more difficult to meet.

A number of different sound spectra can combine to the same overall dBA (1), as shown on Figure 1, but guaranteeing not to exceed a certain level in each of eight, or nine octave bands means that the manufacturer has nine chances to be in violation instead of one — even though he has met the required overall dBA level.

The room constant at the purchaser's installation may be different than at the manufacturer's plant

Purchasers are interested in the noise a machine produces in their own plant, and not on a manufacturer's test stand. But the sound pressure level measured in the purchaser's plant, depends upon the room environment there, and how reverberant it is. It may be different than the environment in the manufacturer's plant, and the measured sound levels there can not be guaranteed, unless the actual "room constant" is known.

For this reason, manufacturers usually state estimated or guaranteed sound levels "under free-field conditions." What they really mean is "under conditions of a free-field over a reflecting plane."

Free-field conditions cannot be obtained in the manufacturer's plant either, so there is a question of how much noise the machine really produces — under any condition.

Octave band sound pressure levels "under free field conditions" can be estimated with reasonable accuracy by applying certain correction factors to the measured levels, as shown below:

1. Measure octave band sound pressure levels according to ANSI S5.1-1971 (2), Test Code for the Measurement of Sound from Pneumatic Equipment. This Code states that, in the case of stationary equipment, measurements shall be made at each end of the equipment, and at the centers of the sides of each casing.

2. At each microphone location, move the microphone away from the machine, in a direction perpendicular to the axis of the machine, and note the maximum drop-off in sound pressure level that can be obtained, in each octave band of interest.

3. At each microphone location note the distance from the machine where the maximum drop-off occurred, in each octave band of interest. (That is, the distance beyond which no further decrease in sound pressure level occurred.)

4. From Figure 2, determine the Correction Factor (1) to be subtracted from the measured octave band sound pressure level to obtain the approximate free-field level.

5. Calculate the overall A-Weighted sound level (dBA) by applying the A-Network Corrections to each of the corrected free-field levels above, and then combining the octave band components.

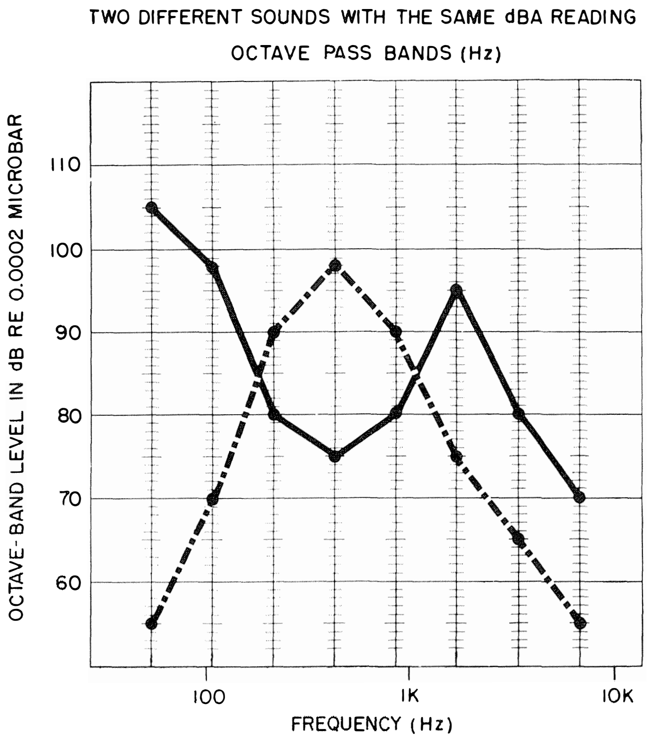

Figure 1. Two Different Sounds With the Same dBA Reading.

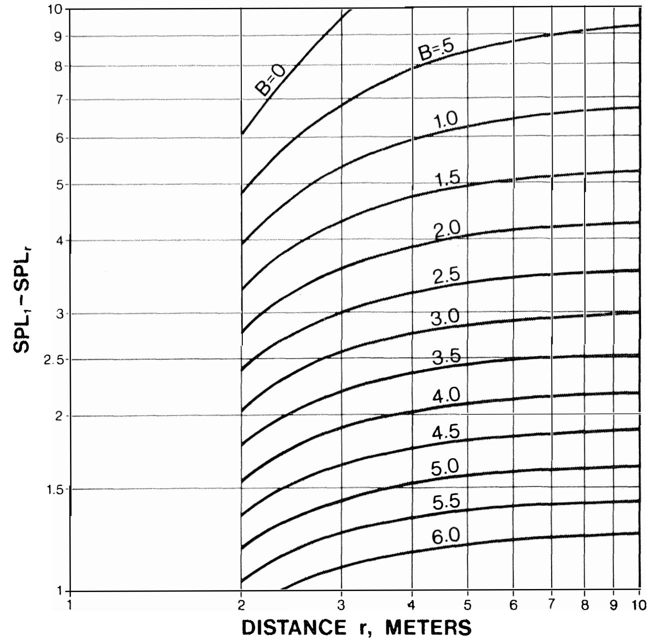

Figure 2. Correction Factors for Estimating Free-Field Sound Pressure Levels.

EXAMPLE:

1. The sound pressure level at location 1, in the 500 Hz octave band, is 92 dB, at a distance of 1 meter from the machine. machine.

2. As the microphone is moved away from the machine, the sound pressure level in the 500 Hz band decreases to 89dB, at a distance of 3 meters from the surface of the machine.

3. From Figure 2, the correction factor is found to be 2.5 dB.

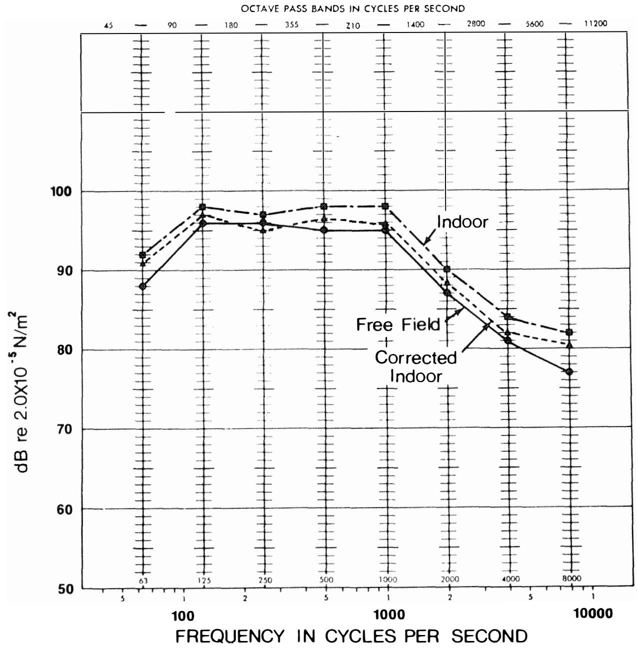

Figure 3. Machine No. 1 — Sound Pressure Levels Corrected to Free-Field Conditions.

4. Therefore the approximate free-field sound pressure level in the 500 Hz octave is:

$$92\text{ dB} - 2.5\text{ dB} = 89.5\text{ dB}$$

5. The equivalent overall dBA sound level may be calculated by subtracting the appropriate A-Weighting correction in each corrected octave band, and then combining the corrected octave band levels.

This procedure is not intended to give laboratory accuracy, of course. It takes room constant into consideration, and makes a correction for it. It is certainly better than no correction at all, and the method has been tested on small, medium size, and large machines. Figures 3, 4 and 5, show typical test results.

Sometimes sound power level is best

A-Weighted sound levels are all that are needed to determine compliance with the OSHA occupational noise exposure regulation, and they can be measured quite simply at a machine operator's location. Not quite so simple, however, is the prediction of noise contours within a plant or refinery area, or the estimation of industrial plant or refinery boundary sound levels, when many different machines are in operation, at various locations within the boundaries. Sound power levels are preferred for this. The problem is determining the sound power level in the first place.

More care is required to determine sound power levels than to measure sound pressure levels. Sound power levels must be calculated from measured sound pressure levels at a number of specific locations around the machine, and the calculated values can not be more accurate than the measured values. In fact, since additional steps are required in the calculation process, there are more chances for error. In spite of this sound power is a very useful quantity to have when making acoustical calculations. It is practically independent of room environment, and independent of distance from the machine. The procedure for determining it, though, is not independent of room constant, and that is where a major problem exists in practice. Because of its growing importance in noise control

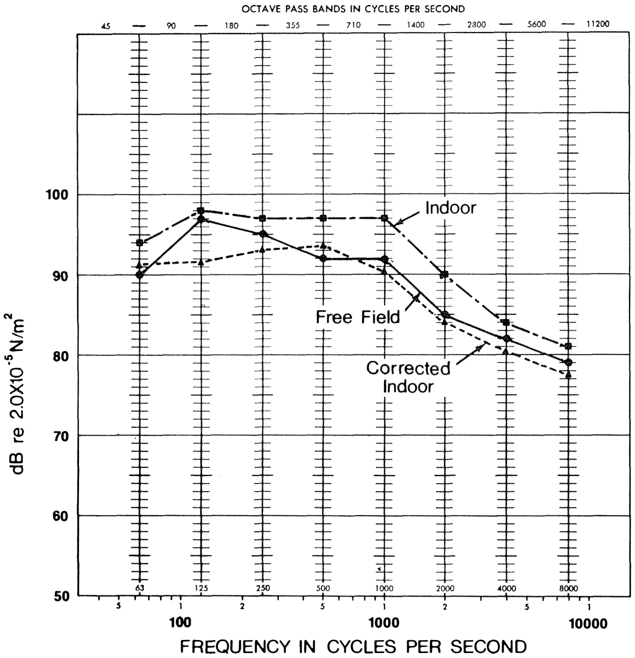

Figure 4. Machine No. 2 — Sound Pressure Levels Corrected to Free-Field Conditions.

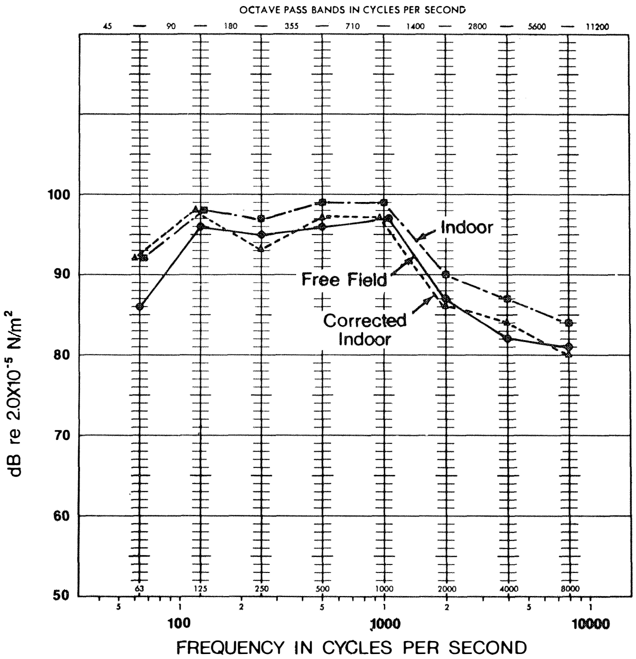

Figure 5. Machine No. 3 — Sound Pressure Levels Corrected to Free-Field Conditions.

regulations, both in the United States and Europe, consideration should be given to some of the factors involved in determining sound power in industrial environments, and the accuracy that can be expected from the various procedures for obtaining it.

Sound power determination

1. For accurate results, sound power level should be determined in either a free field, an anechoic room, or a reverberation room. Large stationary machinery cannot be tested in any of these three environments, and must be tested either in the manufacturer's plant or on the purchaser's property, under conditions which are far from ideal. In fact some machines are installed in locations where it is simply impossible to conduct a sound test that has any meaning. Some machines are nearly as large as the room in which they are located. In other cases, other nearby equipment, which cannot be shut down, makes more noise than the machine being tested.

In most cases the problem is not as difficult as it might seem at first, and both octave band sound pressure levels and octave band sound power levels can be obtained with reasonable accuracy.

2. The sound power level of a machine, or sound source, must be calculated from sound pressure levels measured on an imaginary closed surface around the source. This is shown by Equation 1:

$$L_W = L_p + 10 \log \frac{S}{S_o} \qquad (1)$$

where L_W = Sound power level in decibels re 10^{-12} watt.
L_p = Sound pressure level, in decibels re 20 micropascals.
S = Area of the measurement surface in square meters.
S_o = 1 square meter.

3. When the measurement distance is large in comparison with the dimensions of a noise-radiating machine, all sound waves from different parts of the machine come from nearly the same direction, and the sound source can be treated as a "point source."

4. If the measuring surface is a hemisphere over the floor, or reflecting surface, and if the hemisphere has a large radius, the angle between the direction of sound wave propagation and the surface vector is small, and the geometric error is negligible.

5. In general, accuracy increases with the number of measurement locations. For a true non-directional source, one measurement point is sufficient.

6. If the microphone is placed closer to the machine, the number of measurement locations should be increased so that the distance between adjacent positions is not larger than the measurement distance from the machine.

7. In most industrial locations it is impossible to make sound measurements on the surface of a hemisphere whose radius is two or three times the largest dimension of the machine. In fact, in indoor locations, it is usually not possible to have the measurement distance even one times the machine dimension, and it is customary to make sound pressure level measurements at a distance of one meter from the machine. This means that microphones would have to be located not more than one meter apart, and this would result in a large number of measurements.

Several recent investigations have shown that reasonably accurate sound power level determinations can be made when using microphone distances of 0.3 to 1.0 meter from the machine (3,4,5,6).

8. A number of Draft International Standards (7,8) recently developed by the International Organization for Standardization, ISO, recommended that the measurement surface be in the form of a rectangular parallelepiped, at a distance of one meter from a reference surface, which is defined as the smallest possible imaginary rectangular parallelepiped that will just enclose the machine under test.

9. In equation (1) above, S_0 is 1 m^2, simply to keep the ratio of S to S_0 dimensionless. The sound power level, L_W is equal to the average sound pressure level on the measurement surface plus 10 log S.

For most work, the exact area of S is not too important. An error of 25 per cent results in an error of only 1dB.

10. Although there is very little error in using the "box" measurement surface in testing large machinery, there can be some problems in the case of small machines, where the error in measurement area can be much greater than 25 per cent.

In fact the United States recently voted disapproval of the Draft International Standard for pneumatic tools and rock drills (7) because of uncertainty concerning the proper measurement area. This could vary as much as 318 per cent, and produce an error of more than 5dB.

11. Even in the case of large machines, a rectangular parallelepiped has certain deficiencies as a measurement surface. Not all points are equidistant from the reference surface; the corners of the box are farther than 1 meter away. Instead of a sharp cornered box, one with rounded corners should be used, so that it conforms to a Huygens' surface. Huygens' principle states that all points on a vibrating surface may be considered to be the center of a spherical wave whose intensity is proportional to the excitation at that point.

The justification for the sharp cornered box is that it is very nearly correct, it is much easier to calculate, and furthermore, sound pressure levels measured at the corners should be lower than at other points, because they are farther away, and thereby partially compensate for the increased area.

Unfortunately some test codes do not require sound pressure measurements at the corners. Recent ISO standards do require this, however.

12. A calculation, or an estimate, of the room constant is necessary in order to calculate sound power level from measured sound pressure levels. This can be done in several ways:

(a) It can be calculated by estimating the absorption coefficients of the floor, ceiling, side walls, and other items in the room, and estimating the individual areas of each. It is obvious that this technique is not very accurate for industrial plant locations.

(b) It can be determined experimentally by measuring the reverberation time with a microphone, sound level meter, and high speed graphic level recorder. A wide band noise source is stopped suddenly, and the time is measured, in each octave band, or third octave band, for the level to decrease 60 decibels.

(c) A comparison test can be made with another sound source. A laboratory calibrated reference source with known octave band, or third octave band sound power levels can be used in an absolute comparison test, or an auxiliary sound source can be used in a relative comparison test. In both of these procedures the machine under investigation should be moved out while measurements are being made on the reference source. This is obviously impossible, in the case of large machinery, and the technique becomes questionable when it is considered that many different answers are obtained when the reference source is placed at various locations with respect to the machine under test.

13. One of the best techniques is to use the machine under test as its own "reference source" to evaluate the acoustic environment. This is the basis of the "two-surface method."

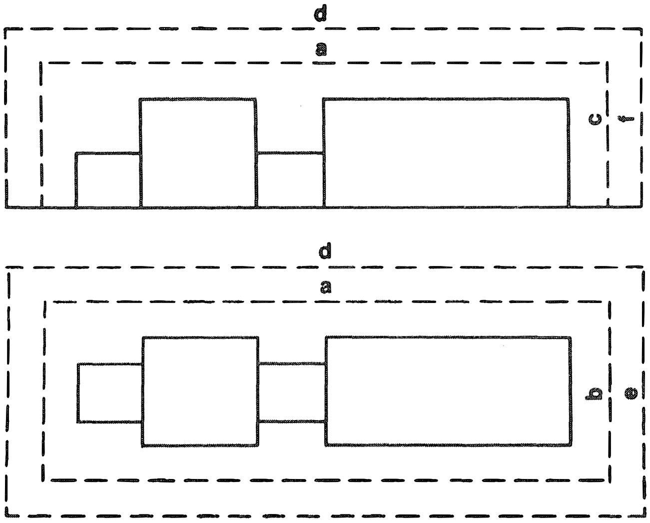

Figure 6. Two-Surface Method Measurement Surfaces.

14. In the "two-surface method" octave band sound pressure levels are measured on the surfaces of two hypothetical rectangular parallelepipeds over the machine being tested.

The second "box" is farther from the machine than the first box, and therefore its area S_2 is greater than the area of the first, S_1, as shown on Figure 6.

The average sound pressure levels on area S_1 will be greater than the average of the levels on S_2, because S_1 is closer to the machine than area S_2.

15. The equations relating sound power level, sound pressure level, and room constant, for the two parallelepipeds are:

$$L_W = L_{p1} - 10 \log\left(\frac{1}{S_1} + \frac{4}{R}\right) \qquad (2)$$

$$L_W = L_{p2} - 10 \log\left(\frac{1}{S_2} + \frac{4}{R}\right)$$

where L_W is the sound power level in dB re 10^{-12} watt.

L_{p1} is the average sound pressure level on surface S_1, re 20 micro-pascals.

L_{p2} is the average sound pressure level on surface S_2 re 20 micro-pascals.

R is the room constant in square meters.

R can be eliminated from these two equations and sound power level can be shown to equal

$$L_W = L_p + 10 \log S_1 - C \qquad (3)$$

where $$C = 10 \log \frac{K}{K-1}\left(1 - \frac{S_1}{S_2}\right)$$

and $$K = 10^{(L_{p1} - L_{p2})/10}$$

16. The environmental correction C, may be calculated mathematically; or it may be found more conveniently from a set of curves, Figure 7 relating the correction factor to $L_{p1} - L_{p2}$ and the area ratio S_1/S_2.

Verification of two-surface method

The Diesel Engine Manufacturers Association, DEMA, recently conducted a series of sound tests to compare sound power levels determined by the two-surface method with those obtained using reverberation time procedures.

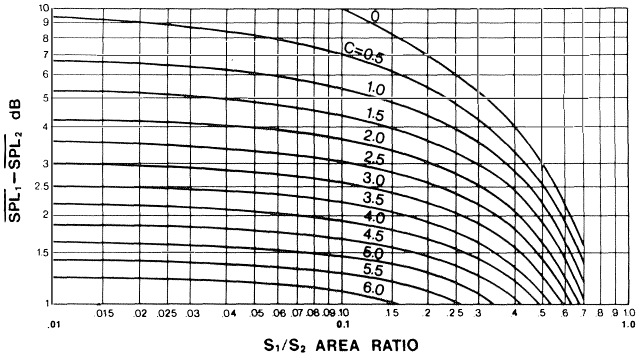

Figure 7. Two-Surface Method Correction Factors.

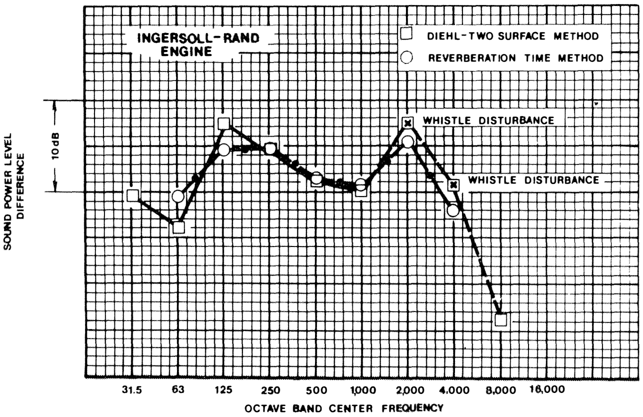

Figure 8. Sound Power Level Comparison — Two-Surface Method vs Reverberation Time Method.

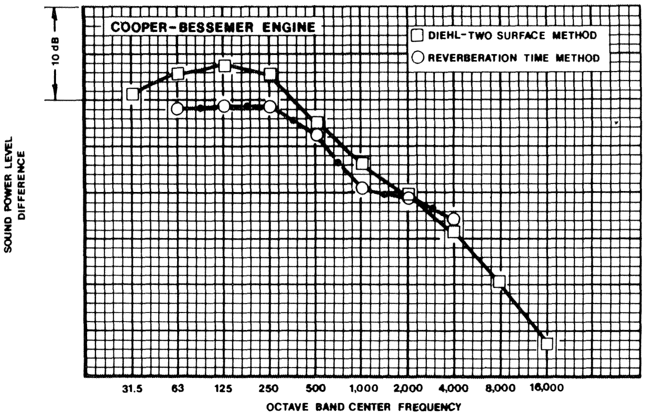

Figure 9. Sound Power Level Comparison — Two-Surface Method vs Reverberation Time Method.

Two different diesel engines were tested in this investigation, one manufactured by Ingersoll-Rand Company and one by Cooper-Bessemer Company. The results of the tests will probably be published later in a technical paper by DEMA.

Figures 8 and 9, taken from the data show that the two methods agree remarkably well.

Sound pressure levels must be measured in any sound power determination — no matter which technique is used. The two-surface method requires a minimum of sound test instrumentation, and can be performed without removing the machine from its installation, and even without shutting it down. It appears to be the best of the practical methods for industrial environments.

Accuracy of results

A guide to the accuracy that can be expected in determining sound power levels is given below. This should be considered whenever it becomes necessary to verify sound estimates or guarantees.

ISO Draft International Standard 3989, covering the measurement of airborne noise emitted by compressor-prime mover units, states that in a free-field over a reflecting plane outdoors, where there are no large interfering surfaces; or in indoor locations where the effect of the environment can be established by either a relative comparison test or a reverberation test, the uncertainty in determining sound power levels is as follows:

Octave-Band Center Frequency Hz	**Standard Deviation dB**
63	5.0 (Approx.)
125	3.0
250	2.0
500	2.0
1K	1.5
2K	1.5
4K	1.5
8K	2.5

These are the standard deviations to be expected under near ideal conditions, and do not include variations in the sound power level of the machine under test.

ISO/DIS 3989 points out that in practical industrial environments "the accuracy stated in the body of this International Standard can not be assured."

What this means is that machinery manufacturers, purchasers, and those who write sound specifications for machinery must take a realistic approach in defining requirements of sound guarantees and in making measurements to verify them.

Figures 8 and 9 show that, at least in these tests, the two-surface method offers a practical procedure for sound power determination, and provides reasonable accuracy — sufficient even for regulatory purposes, provided the regulations also take a realistic approach.

Conclusions and recommendations

1. Sound specifications should be written with a definite objective in mind. This should not be simply to purchase quieter machinery.

For example, the purpose of the specification may be to assure compliance with OSHA regulations at worker locations; or it may be to meet an EPA product noise emission standard so that the machines can be released for distribution into commerce; or it may be to comply with a State or local noise control ordinance stating maximum boundary sound levels.

2. It is a costly mistake to demand more noise control than is necessary.

3. It takes more time, and therefore more money, to get octave band data than it does to get overall dBA data but in many cases octave band levels are necessary.

4. Sound guarantees in terms of octave band levels are much more stringent than those for overall levels only, even though the overall levels are identical in both cases. The guarantee must be met in eight, or nine octaves, instead of at one point.

5. In general, sound power data is more valuable to have than sound pressure information. It is also more costly to obtain. It requires more microphone locations, more data to process, and more calculations than sound pressure level data.

6. The two surface method is one of the best techniques to use for sound power determinations in industrial locations.

7. The true accuracy of any sound power determination made on large machinery in industrial locations is almost impossible to obtain, because there is no way to determine the true accuracy for comparison purposes. In general, accuracy should be within 3 to 5 decibels of the true value, if sound tests are conducted properly.

8. Machinery manufacturers, purchasers, and legislators must take a realistic approach in establishing maximum permissible sound levels.

APPENDIX A

Definitions

Absorption coefficient - The sound absorption coefficient of a surface is the fraction of incident sound energy absorbed or otherwise not reflected by the surface.

Anechoic room - An anechoic room is one whose boundaries absorb effectively all the sound incident thereon, thereby affording essentially free-field conditions.

A-Weighting - Sound level measurements made with the sound level meter set on the A-scale are said to have A-Weighting. This electrical network, which discriminates against low frequencies, has a frequency response similar to that of the human ear.

Decibel - A decibel is the unit of level when the base of the logarithm is the tenth root of 10, and the quantities concerned are proportional to power.

Free field - A free sound field is a field in a homogeneous, isotropic medium free from boundaries. In practice it is a field in which the effects of the boundaries are negligible over the region of interest.

Octave band - An octave is the interval between two sounds having a basic frequency ratio of two.

Reverberation room - A reverberation room is a room having a long reverbation time, especially designed to make the sound field therein as diffuse as possible.

Room constant - Room constant is equal to the product of the average absorption coefficient of the room and the total internal area of the room divided by the quantity one minus the average absorption coefficient.

If there is a large amount of absorption present, the room is said to have a large room constant, and it behaves in a manner similar to a free field. If there is only a small amount of absorption, the room has a small room constant, and its characteristics are nearer to those of a reverberant room.

Sound power level - Sound power level, in decibels, is 10 times the logarithm, to the base 10, of the ratio of a given power to a reference power (usually one pico-watt).

Sound pressure level - Sound pressure level, in decibels, of a sound is 20 times the logarithm, to the base 10, of the ratio of the pressure of the sound to a reference pressure (usually 20 micro-pascals).

Third octave band - A third octave is the interval between two sounds having a basic frequency ratio equal to the cube root of 2.

Two-surface method - A method for determining sound power level from sound pressure levels measured on the surfaces of two hypothetical parallelepipeds enclosing the machine under test.

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