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SOUND POWER MEASUREMENTS
ON LARGE COMPRESSORS INSTALLED INDOORS
- TWO-SURFACE METHOD -

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Sound power ratings of machinery are becoming important for a number of reasons. Industrial installations must comply with recently enacted state and local noise control codes, and sound power ratings are needed to predict compliance. In addition to this, the Federal Noise Control Act of 1972 requires labeling of machinery to show maximum noise emission, and this, logically, may be in terms of sound power.

The sound produced by a compressor cannot be stated in terms of A-weighted sound level alone. Since sound level decreases with distance from the source, this distance must be given, along with the height above the floor where sound measurements were taken. Furthermore, measured noise depends upon the environment where the compressor is installed. A product noise emission label in terms of A-weighted sound level would have to show all this additional information.

In contrast, the sound power level of a machine is independent of measurement distance from the source, and although radiated sound power depends on the acoustic impedance into which it is radiated, it is practically independent of environment for most machinery installations. These properties are the ones that make sound power so desirable in expressing the noise rating of a machine.

In spite of this, sound power level is not often stated, nor even measured for large machinery. The air conditioning industry and certain gas turbine manufacturers provide sound power information, but almost all other large machinery is rated in terms of near-field sound pressure levels. There are several reasons for this:

1. The Occupational Safety and Health Act states hearing damage criteria in terms of A-weighted sound level. Most machinery sound specifications require this information.
2. Until now industrial plant operators have had little or no need for sound power ratings.

3. Sound power levels of large machines are difficult to obtain in most industrial locations.

This situation is changing, and sound power ratings of machinery are becoming more important. Recognizing this, the International Organization for Standardization has decided that all machinery noise measurement standards must include a procedure for determination of sound power level.

The objective, then, is to develop a procedure for determining the sound power level of a machine when it is operating in an industrial environment. This can be done by the two-surface method.

For accurate results, sound power level should be measured in either a free field, an anechoic chamber, or a reverberant field. Most large compressors, and similar industrial machinery cannot be sound-tested in any of these three environments. They must be measured where they are installed, on a customer's property, or in some cases, on the machinery manufacturer's test stand, prior to shipment.

Unfortunately, neither the customer's plant nor the manufacturer's test facility is ideal for sound measurements. 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. Often other nearby equipment, which cannot be shut down makes more noise than the machine being tested. In other instances, it is too dangerous to try to take sound measurements over the top of large rotating machinery, as required in sound power tests.

Not all cases are impossible. There are many machines that can be sound-tested on the job and both octave-band sound pressure levels and octave-band sound power levels can be obtained with reasonable accuracy. Acousticians and noise control engineers cannot back away from these projects because they cannot be done with

laboratory accuracy. Something must be done, and they must do it with the best accuracy possible under actual operating conditions. Measurements in these semi-reverberant environments are of great practical importance to industry.

Sound power levels must be calculated from measured sound pressure levels. Since sound pressure levels are influenced by the environment in which the measurements are made, it becomes necessary to know the effective room constant of the environment. There are several ways to determine this:

First, it may be calculated by estimating the average absorption coefficient of the floor, ceiling, side walls, and other items in the room, and using the appropriate equation for room constant. Although this technique can yield reasonable accuracy for some relatively simple areas, it turns out in the case of most industrial plants that it is no better than simply looking at the location and estimating the room constant directly. In other words, it is not very accurate.

Second, it may be determined by measuring the reverberation time with a microphone, sound level meter, and graphic level recorder. This method is usually not feasible in industrial area. It involves the use of a noise source that is stopped quickly; the time for the level to decrease by 60 dB is measured. High machinery noise precludes the use of most sound sources; attempts to get around it, such as by firing a gun as the noise source, are usually not acceptable to plant operators.

Third, the effect of the environment may be determined by either a calibrated sound source and an absolute comparison test, or by an auxiliary sound source in a relative comparison test. In these methods, the machine under test should be moved out while measurements are being made on the reference source. This is obviously impossible, and the technique loses its value when it is found that many different answers are obtained by placing the reference sources at various locations with respect to the machine under test. Furthermore, the sound produced by available reference sources is much too low to make them usable in most industrial areas.

There is one technique that is feasible and that is to use the machine itself as the sound source.

First consider the equation relating sound pressure level, sound power level, and room constant in a semi-reverberant

room

$$SPL - PWL = 10 \log \left[\frac{1}{2\pi r^2} + \frac{4}{R} \right] + 0.1$$

where,

SPL is sound pressure level, in decibels,

re $2.0 \times 10^{-5} \text{ N/m}^2$;

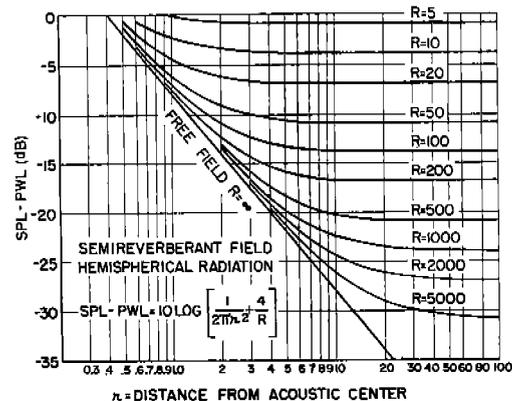
PWL is sound power level, in decibels,

re 10^{-12} W ;

r is the distance from the source, in meters; and,

R is the room constant, in square meters.

This equation can be plotted in a series of curves for various combinations of r and R.

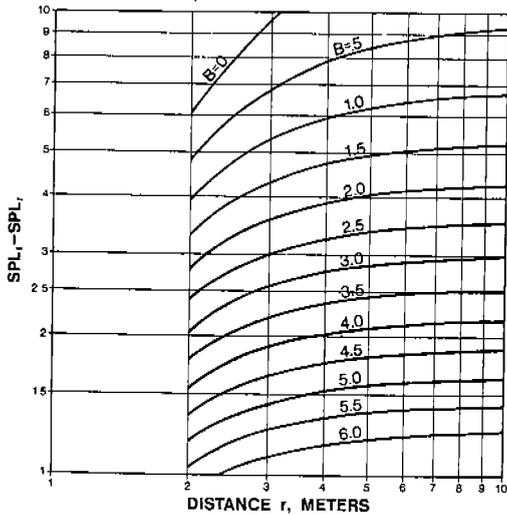


It can be seen from these curves that in the case of a small source, the decrease in sound pressure level with distance provides a means for determining the effective room constant of the area.

With this reasoning, a set of correction factor curves can be obtained by plotting $SPL_1 - SPL_r$ on the vertical axis and r, the distance from the source, on the horizontal axis. SPL_1 is the octave-band sound pressure level at a distance of 1 m from the nearest major surface of the machine, and SPL_r is the octave-band sound pressure level at a distance of r (in meters).

The curves, then, can be used to obtain a correction factor to be subtracted from the octave-band sound pressure levels measured in the semi-reverberant room. From this, the approximate level that would be measured in a free field can be obtained.

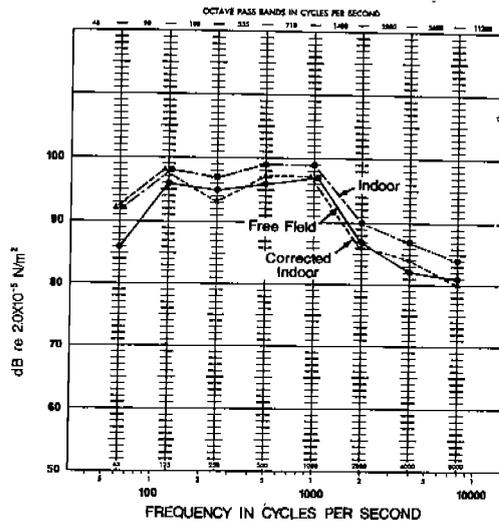
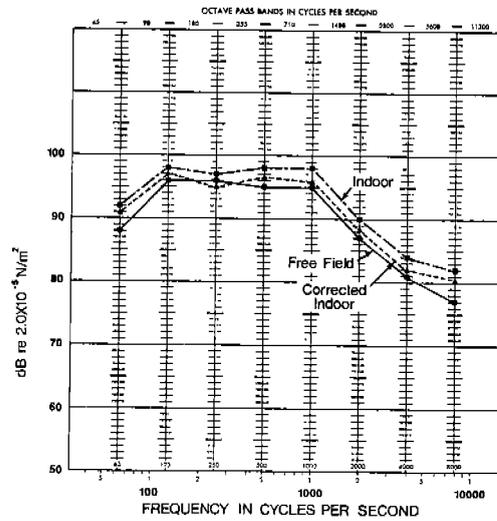
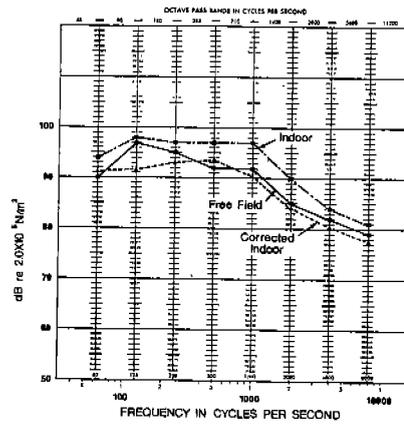
To check the correction factor's validity, an ILG sound source was tested in a free field. Next, it was tested indoors in



various locations in a semi-reverberant field. At each microphone location, measurements were made at a distance of 1 m, and then the microphone was moved away from the sound source in a direction perpendicular to the axis of the machine. Then the maximum decibel drop-off was measured in each octave band of interest. At each microphone location, the distance from the source was noted where the maximum decibel drop-off occurred. The intersection of the maximum decibel drop-off and the distance from the source where it occurred determine the correction factor for that microphone location. When the corresponding correction factor was subtracted from the indoor measurement, the result came surprisingly close to the free-field measurement.

The method was then tried on various sizes of portable air compressors that could be sound-tested outdoors, and then moved indoors to a semi-reverberant location, and tested again. Finally, a large diesel-engine-driven compressor unit, approximately 30 feet long, 8 feet wide, and 12 feet high, mounted on a tractor trailer was tested in the same way. In most cases, the corrected indoor sound measurements were within 1 or 2 dB of the free-field measurements, even though the machines were far from point sources.

In using the method, each microphone location was treated as though it measured the noise from a single source. A correction factor was obtained for each octave band of interest, at each microphone location. The procedure showed that it is possible to use a machine itself as a means for obtaining a correction factor to adjust indoor sound pressure level measurements to approximately free-field conditions.



It was thought at first that a second correction factor should be used to correct for the physical size of the machine under test, since distance should be measured from the acoustic center of the machine

instead of from the nearest surface of the machine. Application of the second correction factor did not seem to be justified, however; actually, it seemed to make the comparison worse in most cases.

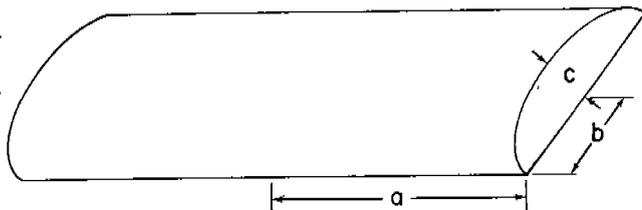
A criterion frequently used in sound power level determinations requires that, in order to be out of the near field, measurements should be made at a distance not less than twice the largest dimension of the machine under test. In measurements made over a reflecting plane, the minimum distance is sometimes increased to four times the largest dimension of the source.

This criterion may be followed in laboratory tests on small machines, but it almost never can be met in industrial plants. Furthermore, recent investigations have shown that reasonable accuracy can be obtained with microphone distances as small as 1/4 m from the machine.

One method that has been proposed for determining the sound power level of a large machine, using near-field measurements, is the following:

1. measure sound pressure levels around the machine and over the top at a distance of 1 m from the nearest major surface of the machine, assuming that the measurements were made on the surface of one half of an elliptical cylinder over the machine;

**SOUND POWER MEASUREMENT
LARGE MACHINERY
AREA OF EQUIVALENT HEMISPHERE**



2. calculate the radius of a hemisphere that has the same surface area as the half cylinder-

lateral area of entire elliptical cylinder = perimeter of end X length
 perimeter of elliptical end = $\pi(b + c)$
 lateral area of cylinder = $2\pi a(b + c)$
 lateral area of half cylinder = $\pi a(b + c)$
 area of equivalent hemisphere = $2\pi r^2$

Then,

$$2\pi r^2 = \pi a(b + c)$$

$$r^2 = \frac{a(b + c)}{2}$$

$$r = \left[\frac{a(b + c)}{2} \right]^{1/2}$$

3. calculate the average sound pressure level, SPL, in each octave band of interest; and,

4. calculate the sound power level, assuming that measurements had been made at a distance of r from the acoustic center, using

$$PWL = \overline{SPL} + 20 \log r + 7.80, \text{ re } 10^{-12} \text{ w.}$$

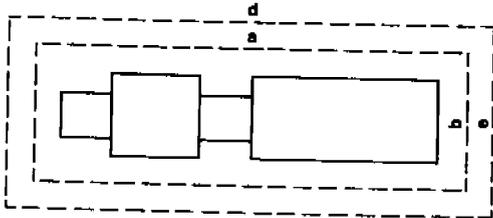
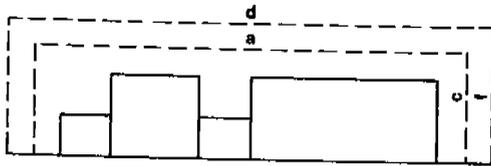
There are several deficiencies with this method. First, there is no correction for the environment, and calculated sound power levels can never be more accurate than the sound pressure levels from which they were calculated.

Another deficiency is that in the case of machines with certain dimensions, the distance r turns out to be less than the machine dimension, meaning that sound power levels were calculated on the basis of an average sound pressure level, measured inside the machine. This, of course, is physically impossible.

The two-surface method for determining sound power level overcomes these deficiencies. It provides an adjustment for room environment; it does not rely on an "equivalent radius". True, it cannot be applied in all cases, but when it can be used, it is as accurate, or more accurate, than other industrial sound power procedures.

In this method, octave-band sound pressure levels are measured on the surfaces of two hypothetical parallelepipeds over the machine being tested. The second imaginary "box" is farther away from the machine than the first, and therefore its area, S_2 , is greater than that of the first, S_1 .

Although the sound power level is constant, the average of the sound pressure level measurements for area S_1 will be greater than the average for area S_2 because S_1 is closer to the source than area S_2 .



$$PWL = SPL_1 - 10 \log \left[\frac{1}{S_1} + \frac{4}{R} \right]$$

$$PWL = SPL_2 - 10 \log \left[\frac{1}{S_2} + \frac{4}{R} \right]$$

where,

SPL_1 is the average of the sound pressure level measurements for area S_1 ;

SPL_2 is the average of the sound pressure level measurements for area S_2 ; and,

R is the room constant.

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

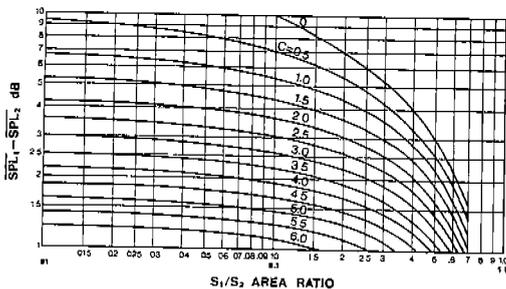
$$PWL = SPL_1 + 10 \log S_1 - C$$

Where,

$$C = 10 \log \frac{K}{K-1} \left[1 - \frac{S_1}{S_2} \right];$$

$$K = 10^{(SPL_1 - SPL_2)/10}$$

The environmental correction, C , may be calculated mathematically, or it may be found more conveniently from a set of curves relating the correction factor to $SPL_1 - SPL_2$ and the area ratio S_1/S_2 .



Accuracy of the method can be improved, theoretically, by increasing the number of measurement locations. In practice, it turns out that it is generally unnecessary

to use a great many measurement points. To demonstrate this, several different compressor types with entirely different operating principles were tested in three ways to determine their octave-band sound power levels.

First, a six-point hemispherical array was used. Second, microphone locations were arranged in a 17-point half-cylinder array. Finally, microphones were located as stated in ANSI S 5.1, "Test Code For The Measurement Of Sound From Pneumatic Equipment". This code prescribes microphone locations at each end and at the centers of the sides of the machine, plus a point at the location of maximum dBA.

The dBA readings were identical in all three methods. The differences in octave-band sound power levels between any two methods were usually 1 or 2 dB.

FREE FIELD
SOUND POWER LEVEL RE 10^{-12} W
MACHINE AV25

① Octave Band	② 6 Point Hemisphere	③ 17 Point Half-Cylinder	④ Difference ①-②	⑤ ANSI S5.1	⑥ Difference ⑤-②
dBA	108	108	0	108	0
63	90	89	-1	90	0
125	87	89	+2	87	0
250	106	106	0	105	-1
500	106	107	+1	107	+1
1K	100	101	+1	100	0
2K	97	98	+1	97	0
4K	99	96	-3	94	-5
8K	86	85	-1	85	-1

Conclusions can be drawn:

1. Tests are underway to accumulate data in the two-surface method to prove its accuracy. All indications are that this new procedure will be the best way to determine sound power levels of large machinery installed indoors in actual industrial and semi-reverberant locations.
2. Measurement of sound pressure levels on two separate hypothetical surfaces provides a means for evaluating the environmental correction.
3. Previous tests have shown that the "dB drop-off" can give a fairly reliable measure of the effect of the environment. The two-surface method utilizes this principle.
4. Except for cases where strong directivity effects are encountered, a large number of microphone locations are not required.
5. It is understood that in conducting these tests, the usual precautions and good engineering practice must be observed, such as separation or isolation of unwanted noise sources, provision of additional sound absorption on hard reflecting surfaces, and assurance that background noise does not interfere.