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# EQUIPMENT SOUND POWER MEASUREMENT IN REVERBERATION ROOMS

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PURPOSE OF MEASUREMENTS. The engineering approach to sound control in buildings consists of setting appropriate design goals for the sound pressure level in the various rooms and controlling either the sound power output of the sources, or the sound transmission from the sources to the listeners, or both, to meet these goals in the most economical manner. Sound control calculations are based on the statistical concepts of acoustic energy buildup in rooms and acoustic power flow through walls, both of which are functions of frequency. To be compatible, data for the various sound sources must therefore be expressed in terms of sound power spectra.

Equipment sound power spectra can be determined in three different acoustic measurement environments, each having certain advantages and certain limitations: Measurements in the free field provide not only acoustic power spectra but also directivity information. The facility and test effort, however, are relatively costly and hard to justify since directivity information is usually not needed. Measurements in the near field do not require any special facilities and are thus ideal for on-site tests. The test effort, however, is highest due to the large number of measurement points and corresponding data processing required.

Measurements in the reverberant field require only moderate facilities and the least amount of effort. This is particularly important whenever many different models or samples have to be tested at many different operating conditions, as for sound rating of typical air conditioning system components.

ACCURACY CONSIDERATIONS. The most important considerations in preparing a test standard are the accuracy required by the intended use of the data as well as the total cost, including not only the facility and instrumentation but also the effort required for measurements, calibration, and data processing. Acoustic ratings for many industrial products are used not only for system design but also for selection amongst several competitive makes. The latter requires the greatest accuracy, a standard deviation of ± 2 dB being desirable in the 500, 1000 and 2000 Hz octave bands.

In order to achieve this accuracy, the standard deviation of each potential error source must, of course, be kept within correspondingly tighter tolerances.

The following error sources must be considered:

1. Incomplete space averaging of the sound pressure in the reverberant field.
2. ~~Limited room volume.~~
3. Systematic and random variances of calibration.

SPACE AVERAGING. The sound pressure in a reverberant field has local maxima and minima, particularly when the sound contains discrete frequency components.[1] Fig. 1 shows that use of a single microphone would result in excessive errors even for broad band sound. By averaging N samples of the sound field taken at different locations, the standard deviation will be reduced by a ratio of $\sqrt{N}$. Nine samples thus provide a standard deviation of ± 1.5 dB for discrete frequency sound.

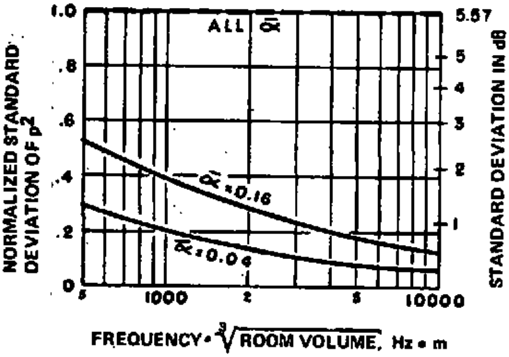


FIG. 1 ... UNCERTAINTY IN MEASURING SOUND PRESSURE WITH SINGLE, ARBITRARY MICROPHONE POSITION. ADAPTED FROM REF. 1 AND 2.

——— 1/3 Octave Bands of Broad Band Sound

— — — Discrete Frequency Sound

Taking this many separate readings and computing the average is quite time consuming. A more practical solution is to average (or integrate) the filtered and squared microphone signal automatically while the microphone traverses a suitable path. Theoretically this is equivalent to averaging $N = 1 + 2X/\lambda$ statistically independent samples where X is the length of the traverse and $\lambda$ is the wavelength.[2,3]

Experimental investigations[4] have shown that continuous averaging is somewhat better than predicted by theory. A widely used microphone traversing mechanism with a 10 foot path thus provides better than ± 1.5 dB standard deviation for discrete frequency sound at frequencies above 450 Hz. At lower frequencies additional averaging means are required. These may take the form of multiple and two-dimensional microphone traverses or of rotating sound diffusers, each of which can double or triple the equivalent sample size.[4]

ROOM VOLUME. The acoustic power output of any given sound source is a function of the impedance presented by the surrounding medium. Reverberant room modes may increase or decrease this impedance depending on the location of the source as well as on its frequency in relation to the frequencies of the room modes. If the room is very large compared to the wavelength, there will be so many modes at a given frequency that the effects of individual modes cancel out. Fig. 2 shows the standard deviation for simple sources of both discrete frequency sound and of random noise.[5] It is seen that the expected error becomes negligible if the room is large enough and that the absorption coefficient, $\bar{\alpha}$, should not be extremely low.

Other factors such as room shape and proportions do not seem to have any major effect on the accuracy.

Computer studies[6,7] have confirmed the theoretical curves shown in Fig. 2 and have also shown that the greatest contribution to the standard deviation comes from source positions within a quarter wavelength of the walls. For the remainder of the room, the standard deviation for discrete frequency sound sources was found to be only 70% of that shown in Fig. 2.

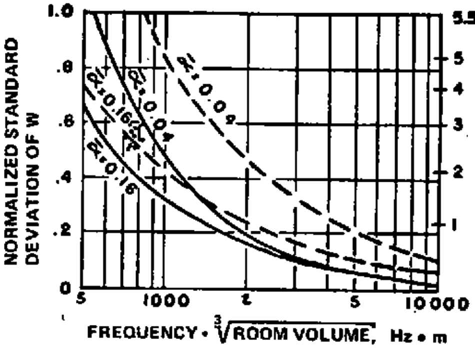


FIG. 2 ... UNCERTAINTY OF SOUND POWER OUTPUT AT A SINGLE, ARBITRARY SOURCE POSITION FOR SIMPLE SOURCES. ADAPTED FROM REF. 5.

——— 1/3 Octave Bands of Broad Band Sound

– – – Discrete Frequency Sound, Theory

∴ Ditto, Computer Studies, Unrestricted Positions

Further improvements can be obtained by installing a large rotating sound diffuser which averages the radiation impedance[7] by continuously shifting the modal patterns in the room. It should be noted that these effects cannot be obtained with fixed diffusers but only with moving ones. The dimensions of the diffuser should be no less than a wavelength and the speed of rotation should be as high as possible, 15 to 30 rpm having been used successfully.[7,8]

CALIBRATION. The space distributions of the impedance and of the pressure field are not entirely random: both have always maxima at the walls. Averages for source and microphone positions spaced at least 1/4 wavelength from the walls are therefore consistently lower than the true space average. A correction factor of $\left(1 + \frac{S\lambda}{8V}\right)$ has been suggested for the pressure squared[10] and should also be applicable to the impedance. Total corrections are tabulated below:

| Frequency (for 180 $m^3$ room) | 50 Hz | 100 Hz | 200 Hz | 500 Hz |
|---|---|---|---|---|
| dB Correction | +5.7 | +3.3 | +1.8 | +0.8 |

The need for such correction can be avoided by calibrating the room with a reference sound source of known free field sound power level, $L_{Wr}$. The equipment sound power level, $L_{We}$, is then calculated for each frequency band using the following relation:

$$L_{We} = L_{pe} - L_{pr} + L_{Wr} \qquad (1)$$

Since equation (1) involves only the difference between the sound pressure levels $L_{pe}$ and $L_{pr}$ measured with the equipment and with the reference sound source, errors in the absolute calibration of the instrumentation cancel out.

A widely used aerodynamic reference sound source is shown in Fig. 3. Sources of this type have no tendency to wear or age and are therefore very stable and reproducible. Five different specimens of this reference sound source purchased over a ten year interval were recently tested and all of them were found to be within ±0.5 dB of the mean over the entire frequency range from 100 to 10,000 Hz.

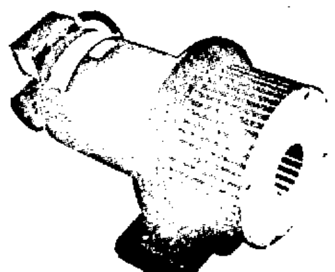

FIG. 3 ... REFERENCE SOUND SOURCE
MODEL NO. 181-012ZA
AVAILABLE FROM ILG INDUSTRIES, INC.,
2850 NORTH PULASKI ROAD,
CHICAGO, ILLINOIS, 60641, USA
115/230 VOLT SINGLE PHASE 1/4 HP MOTOR
3410 RPM ± 20 AT 60 HZ
2900 RPM ± 20 AT 50 HZ
SEE REF. 9 FOR CALIBRATION

EXPERIMENTAL DETERMINATION OF ACCURACY. The total a uracy depends on the standard deviations associated with the tests of the unknown equipment ($\sigma_e$), the test with the reference sound source ($\sigma_r$), and the calibration of the reference sound source ($\sigma_c$):

$$\sigma_{total} = \sqrt{\sigma_e^2 + \sigma_r^2 + \sigma_c^2} \quad , \qquad (2)$$

As discussed above, $\sigma_c$ can be assumed to be no greater than 0.5 dB. $\sigma_e$ and $\sigma_r$ are the combined effects of incomplete space averaging and limited room volume. While the preceding discussions provide guidelines for minimizing these errors, the actual accuracy of a facility should be determined experimentally.

$\sigma_r$ can be estimated easily, for each frequency band, from the averaged band sound pressure levels, $L_1$ to $L_n$, taken with the chosen microphone traverse, for n different positions of the reference sound source:

$$\sigma_r = \sqrt{\frac{(L_1-m)^2 + (L_2-m)^2 + \ldots + (L_n-m)^2}{n-1}} \qquad (3)$$

where m is the arithmetic average of $L_1$ to $L_n$. n should be at least 5 and preferably 8 to 10. If there is a moving diffuser, it should be operating during the test.

$\sigma_e$ for broad band sound equals $\sigma_r$. For discrete frequency sound an estimate of $\sigma_e$ is most easily obtained by the method described in Annex C of Ref. 11. This procedure takes frequency effects into account directly and space effects indirectly through analogy between the frequency and space domains.

Experience indicates that the following accuracy is obtainable in reverberation rooms of 200 to 300 $m^3$ volume equipped with a 3 m long microphone traverse and with a large rotating diffuser:

| Octave Band | Standard Deviation | |
|---|---|---|
| Center Frequencies | Broad Band Sound | Discrete Frequency Components |
| 63 Hz | ± 5 dB | ± 6 dB |
| 125 Hz | ± 3 dB | ± 4 dB |
| 250 and 500 Hz | ± 2 dB | ± 3 dB |
| 1000 and 2000 Hz | ± 1.5 dB | ± 2 dB |
| 4000 and 8000 Hz | ± 2 dB | ± 2 dB |

The accuracy for broad band sounds containing discrete frequency components is between the values shown in the middle and the right-hand column, depending on the intensity of the discrete frequency components relative to the broad band component.

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