ANALYSIS OF ERRORS IN SOUND INTENSITY SCANNING TECHNIQUE FOR THE DETERMINATION OF SOUND POWER OF NOISE SOURCES

G. Krishnappa[1], S.E. Keith[1, 2] and S.H.P Bly[2]

[1]National Research Council, Institute for Machinery Research, Bldg. M-16, Montreal Road, Ottawa, Canada K1A 0R6

[2]Bureau of Radiation and Medical Devices, Department of Health and Welfare, 775 Brookfield Road, Ottawa, Canada K1A 1C1

Introduction

Sound intensity measurements are being increasingly used to determine sound power of noise sources. Assessment of measurement uncertainties is important for wider use of this technique.

This paper summarizes a recent study carried out to examine the bias and random errors associated with the scanning intensity technique under complex acoustic field conditions.[1] Based on experiments and theoretical formulations, errors were calculated for a complex acoustic source. Measurement errors under extraneous noise conditions were also examined.

1. Error Formulae

The two field indicators stipulated in ISO/WD9614-2[2], are the pressure-intensity indicator (F_{pI}), and negative partial power indicator ($F_{+/-}$). F_{pI} (or F_3 in ISO 9614-1[3]) is a key to measurement evaluation in this paper, and is defined by ten times the logarithm of the ratio of pressure to intensity. The latter indicator $F_{+/-}$ (or F_3-F_2 in ISO 9614-1[3]), warns of possible errors due to external noise sources. In a diffuse sound field, both can be estimated from the measurement environment.

The total pressure over the measurement surface can be estimated by the sum of the diffuse and direct pressures. The diffuse mean square pressure averaged over the measurement surface may be inferred from Jacobsen[4] as:

$$\frac{S_0 c T_{60}}{6V\ln 10}\,\frac{L_{W_I}+L_{W_{EN}}}{S_0}\rho c \tag{1}$$

where c is the speed of sound, ρ is the air density, L_{W_I} is the source sound power, $L_{W_{EN}}$ is the sound power from all external noise sources, S_0, V and T_{60} are the measurement room surface area, volume, and reverberation time, respectively.

To approximate the direct pressure, assume the vector intensity is perpendicular to the measurement surface, and near field effects are minimal. Under free field conditions the mean square pressure over the measurement surface is approximated by:

$$(L_{W_I}+2yL_{W_{EN}})\,\rho c/S_0 \tag{2}$$

where y ($0<y<1$) is a weighting representing the fraction of the total external noise power that passes directly through the measurement volume (i.e., $yL_{W_{EN}}$).

If expression (1) is large compared to expression (2), and the average intensity through the measurement surface is (L_{W_I}/S_0), then using expression (1), F_{pI} can be approximated as:

$$F_{pI}\approx 10\log\left(\frac{S_0 c T_{60}}{6V\ln 10}\,\frac{L_{W_I}+L_{W_{EN}}}{L_{W_I}}\right) \tag{3}$$

The second indicator, $F_{+/-}$, is the ratio of the total sound power to the source sound power passing through the measurement surface. $F_{+/-}$ is a maximum when external noise enters and exits through separate, infinitesimal areas. Thus $F_{+/-}$ is described by:

$$F_{+/-} \le 10\log\left((L_{W_I}+2yL_{W_{EN}})/L_{W_I}\right) \tag{4}$$

For valid measurements $F_{+/-}$ should be less than 3 dB.[2,3]

Using F_{pI}, the maximum measurement bias error (L_{ε_B}) due to phase errors is given by Gade:[5]

$$L_{\varepsilon_B}=-10\log(1-10^{0.1(-\delta_{pI_0}+F_{pI})}) \tag{5}$$

where δ_{pI} is the pressure-residual intensity index[2,3].

Making use of equation (3), under diffuse field conditions the theoretical random errors (ε_{BT} and ε_S) due to the bandwidth time (BT) product[5] and sampling errors[4] are:

$$\varepsilon_{BT}=\pm 0.42(K+1)/\sqrt{BT} \tag{6}$$

$$\varepsilon_S=\pm K/\sqrt{N_{eq}6(1+BT_{60}/(3\ln 10))} \tag{7}$$

where B is the analysis bandwidth, T is the total measurement time, K is the pressure-intensity ratio (i.e., F_{pI}=10log|K|), and N_{eq} is the equivalent number of uncorrelated measurements along the scanning path, approximated by:[4]

$$N_{eq}\approx(2l/\lambda)/[1+(\pi/2)l\lambda/S_0] \tag{8}$$

where l is the total length of the scanning path, and λ is the wavelength of sound at the frequency of interest.

In constructing the total error estimate (L_ε), errors were converted to decibels and combined as follows:

$$L_\varepsilon=\pm L_{\varepsilon_B}+10\log\left[1\pm\sqrt{\varepsilon_{BT}^2+\varepsilon_S^2}\right] \tag{9}$$

3. Apparatus

The sound source consisted of two identical loudspeakers separated by 50 cm and mounted in the large face of an undivided closed box baffle. The enclosure dimensions were 1 m² by 0.3 m high. Both speakers were driven from a single white noise source. The electrical input of one speaker was inverted with respect to the other and attenuated by 6 dB.

The sound source was centred on the floor of a 60 m³ room with calculated reverberation time between 1 and 2 seconds. Most room surfaces were made of either concrete or wood.

An external noise source outside the measurement volume was positioned, facing downwards, 1 m over the centre of the sound source. This source used a loudspeaker, of the same type as the sound source, mounted in a 25 litre closed box baffle.

Intensity measurements were made using a Brüel & Kjær type 3519 face to face two microphone intensity probe with 12 mm microphones and either a 12 mm or 50 mm spacer. Data were analyzed using a Brüel & Kjær type 2133, 1/3 octave, real time, constant percentage bandwidth intensity analyzer.

4. Procedure

Scanning acoustic intensity measurements were made according to ISO/WD9614-2[2] over a (box like) measurement surface located 40 cm from the sound source enclosure. Scan lines were oriented lengthwise along the surface with a 20±3 cm separation between successive scans. Each surface was manually scanned 6 times at a speed of 30 cm/s for at least 20 seconds. Measurements were repeated if differences between power levels from any single surface varied by more than 0.5 dB.

Phase measurements were within manufacturer's specifications, and variations in calibration levels were negligible. These were verified before each day's testing, at 250 Hz, using a pistonphone and a Brüel & Kjær type 3541 acoustic intensity coupler.

5. Results and Conclusions

Dominance of the diffuse field, and hence applicability of the above equations, was verified by both calculation and comparison with anechoic chamber measurements.[6] Calculations showed excellent agreement with individual measured values of F_{pI} and total error. Most differences could be attributed to measurement errors caused by the external noise source.

Measurements with external noise power over 6 dB greater than the power output of the sound source were inadmissible according to ISO/WD9614-2[2] (as indicated by $F_{+/-}$, and the dynamic capability of the analyzer[2,3]). It should be noted that, calculated $F_{+/-}$ values (eqn. (4), y=1) suggest external noise levels greater than -3 dB should be inadmissible. The difference between measured and calculated $F_{+/-}$ suggests external noise must enter and leave through the same measurement surface.

Results for 6 dB external noise are shown in Figure 1. Calculated errors used measured F_{pI} values. Measured errors were estimated from results without external noise. Below 800 Hz, results are typical. The measured data are conservatively approximated by the total calculated error (due mainly to equation (7)). Although measured errors are unacceptably large, they appear random, making them identifiable by a partial power repeatability test[2,3] and correctable by continued scanning of the surface. This contradicts equation (8) which, at low frequencies, indicates little effect of an increase in the scanning path length.

Above 1.2 kHz measured errors reach the limits of engineering grade accuracy[2,3] (± 3 dB). These errors reduced to calculated values for external noise power levels below -1 dB.

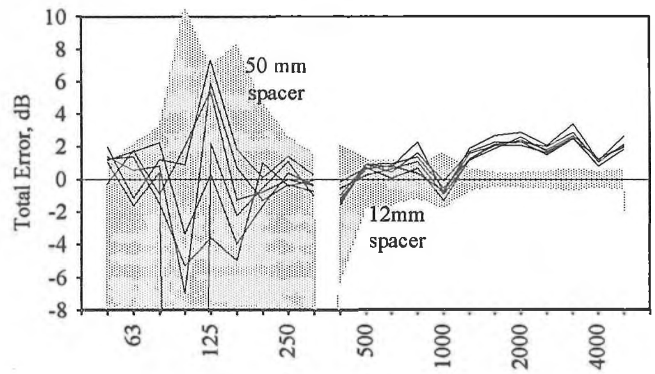

Figure 1: Calculated total error (L_ε) for 6 dB external noise, ; The lines show measured errors for 6 nominally identical tests

The present studies suggest that the procedure given in the ISO scanning document could be used with reasonable confidence to determine sound power of noise sources under moderate extraneous noise conditions.

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