ISO/IEC GUM APPLIED TO ESTIMATION OF SOUND POWER MEASUREMENT UNCERTAINTIES

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1. INTRODUCTION

Over the last 40 years there have been significant improvements in ISO machinery sound power measurement standards using sound pressure. However, measurement uncertainties have essentially stayed the same, representing typical conservative situations. This results in users not reporting these uncertainties because they are too large.

In reality, the ISO standards can under or over estimate measurement uncertainty. The same uncertainty could be assumed regardless of whether the measurement is in a quiet abandoned airstrip, or a noisy crowded outdoor construction site. Using information specific to a given measurement allows a better estimate of uncertainty. This paper implements the methods of the *ISO/IEC Guide to the expression of uncertainty in measurement* [1] (GUM) and the ISO engineering grade sound power standard [2] to show uncertainty calculations for a specific measurement.

2. METHOD

A functional relationship for sound power, L_W , is:

$$L_W = \overline{L_p} + 10\lg\frac{S}{S_0} - K_1 - K_2 + \delta_{\mathrm{mic}} + \delta_{\mathrm{angle}} + \delta_{\mathrm{other}}$$

where $\overline{L_p}$ is the mean sound pressure over a measurement surface with area, S (S_0 = 1 m), and K_2 is an environmental correction equal to the difference between the measured sound level versus the level that would be measured in a hemi free field. The δ 's are additional uncertainties, δ_{mic} is due to sampling, δ_{angle} is due to the difference between intensity and pressure and δ_{other} is due to other factors such as instrumentation or method. K_1 is a background noise correction given by:

$$K_1 = -10\lg\left(1-10^{-0,1\left(\overline{L_p}-\overline{L_{p(B)}}\right)}\right)$$, where $\overline{L_{p(B)}}$ is the mean background noise level averaged over the measurement surface.

Table 1: Sensitivity coefficients and standard uncertainties, where s with subscript is the standard deviation of the quantity in the subscript, and n refers to the number of measurement points.

variable	sensitivity coefficient, c_i	standard uncertainty, u_i
$\overline{L_p}$	$1+1\Big/\left(10^{0,1\left(\overline{L_p}-\overline{L_{p(B)}}\right)}-1\right)$	$s_{\overline{L_p}}$
S	see [2]	
K_1	$-1\Big/\left(10^{0,1\left(\overline{L_p}-\overline{L_{p(B)}}\right)}-1\right)$	$s_{\overline{L_{p(B)}}}$
K_2	1	$K_2/4$
δ_{mic}	1	$s_{L_{p_i}}\Big/\sqrt{n}$
δ_{angle}	$10^{-K_2/10}$	u_{angle} (Fig. 2)
δ_{other}	see [2]	

For each variable, the uncertainty contribution to the sound power, L_W , is $uc_i = u_i \cdot c_i$ where u_i is the standard uncertainty and c_i is a sensitivity coefficient, (Table 1). Sensitivity coefficients are partial derivatives of L_W . The combined standard uncertainty is the summation in quadrature of all uncertainty contributions to L_W .

3. DISCUSSION

Fig. 1 shows the standard uncertainty contributions uc_i for $\overline{L_p}$ and K_1 for an extreme case when the background noise measurement standard deviation, $s_{\overline{L_{p(B)}}}$, is 3 dB. Each uncertainty contribution is calculated from the measurement standard deviation, $s_{\overline{L_p}}$, and sensitivity coefficient, as in Table 1. The bulk of this uncertainty is due to the K_1 correction of the measured levels to account

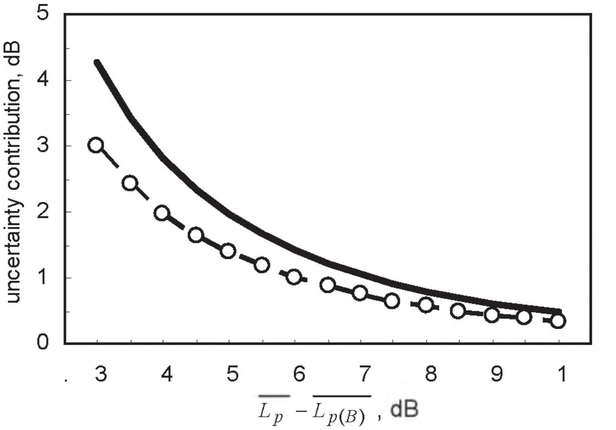

Fig. 1: Standard uncertainty contributions to L_W for an ideal stable source when background noise standard deviation, $s_{\overline{L_{p(B)}}}$, is 3 dB: background noise contribution uc_{K1} (dashed line); source contribution uc_{Lp} (open circles); and their combined standard uncertainty (solid line).

for background noise. For example, if the background noise is not stable, then there is more uncertainty in this correction. Similarly, if the measured noise source levels vary, then the K_1 correction will also introduce uncertainty. In this figure the source was ideally stable (i.e., a reference sound source). However, even measured levels from an ideal source would not be exactly repeatable due to the influence of the background noise on the measurement.

Fig. 1 assumed background noise with a standard deviation, $s_{\overline{L_{p(B)}}}$, of 3 dB to make the combined uncertainty consistent with the standard deviation of reproducibility in the ISO standard [2]. This engineering grade standard has $\overline{L_p} - \overline{L_{p(B)}}$ limited to 6 dB and the associated standard deviation of reproducibility is 1.5 dB, the same as the combined standard uncertainty in Fig 1. Using this standard in an outdoor construction site, background noise standard deviation, $s_{\overline{L_{p(B)}}}$, could easily exceed 3 dB, and the standard uncertainty could exceed the published standard deviation of reproducibility. The situation is similar in other ISO precision and survey grade standards.

ISO also puts a limit on the decibel range of measured levels. For engineering grade, this range is equal to the number of measurement points. Using 10 measurement points a worst case for δ_{mic} occurs when the measured levels are equally split and lie at the upper and lower limits of the allowable range. This situation could occur on a machine with a shielded operator area. This results in $s_{L_{p_i}}$ =5.3 dB and, from Table 1, a standard uncertainty contribution of 1.7 dB. This exceeds the 1.5 dB standard deviation of reproducibility in the standard. A similar situation exists in the precision grade standard.

Measurements close to the source affect δ_{angle} due to an overestimate of sound power, which is proportional to the average component of intensity normal to the measurement surface. Sound pressure obtained on a very large planar measurement surface very close to a very large piston can give a good estimate of sound power, since the sound pressure is equal to the normal component of sound intensity (when both are measured in decibels). However, if the sound was to originate from a point source at the centre of the piston, sound pressure would overestimate the sound power since the direction of the sound intensity at the edges of the measurement surface would be almost parallel to the surface, and the desired normal component would be much smaller. When these two situations are extended to an enclosing measurement surface, the range of uncertainty is given in Fig. 2 as a function of S/d^2 , the ratio of measurement surface area S to the distance, d, between the measurement surface and the source. The shaded area represents the range of values obtained with an infinite number of measurement points on a box shaped measurement surface. The worst case for a cubic 9 point measurement surface from the engineering grade standard falls somewhat above this shaded range, i.e., S/d^2 is 45 and the standard uncertainty is 2.3 dB (for a machine with a point source in the middle of the top edge). Table 1 shows when the environmental correction, K_2 , is zero (such as in a hemi anechoic space) the worst case sensitivity coefficient is 1, with the resulting worst case uncertainty contribution of 2.3 dB. For relatively small sources a hemisphere can be used, which significantly reduces this error, as shown by the hatched area in Fig 2.

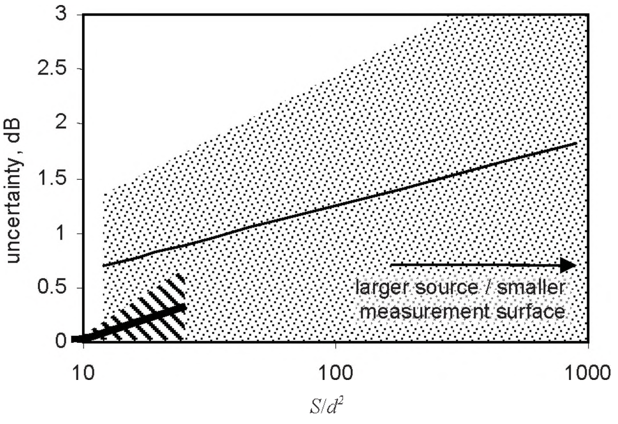

Fig. 2: Standard uncertainty u_{angle} due to approximation of intensity level using sound pressure. Shaded area shows range for infinite number of points over a box measurement surface, where thin line is an average value taken from [3]. The hatched area shows a similar range for a hemisphere measurement surface, with the thick line an average value.

In contrast, the best case scenario for any of the above uncertainty contributions approaches zero dB. Uncertainties in Fig 1 can be reduced by controlling background noise, longer averaging times, or measurement closer to the source. δ_{mic} is reduced by increasing the number of microphone positions, measurement farther from the source or an increase in reverberation time. δ_{angle} is reduced by increasing reverberation time, or a larger preferably hemispherical measurement surface.

4. CONCLUSION

This paper has shown that existing standards can underestimate or overestimate uncertainties. This is entirely appropriate since basic statistics tell us that 5% of measurement situations should differ from the mean by more than 2 standard deviations. However, 20% of measurement situations will be within ¼ of a standard deviation from the mean. Given that it is possible to identify these situations, it seems inappropriate to base uncertainties on a somewhat conservative general case. Using information specific to a given measurement allows a better estimate of uncertainty.

REFERENCES

[1] ISO/IEC Guide 98-3 (1995) Uncertainty in measurement - Part 3: Guide to the expression of uncertainty in measurement

[2] ISO 3744 (1994) Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane

[3]. Probst, W. (1999) Checking of sound emission values. BAuA report, Fb 851, ISBN 3-89701-375-4, Dortmund