On the Accuracy of Sound Power Determination for a Given Level Distribution

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Introduction

Some investigations of the errors of the machinery sound power determination from either sound pressure or intensity measurements are based on the assumption of its independence and random distribution, [1]. Another approach is to apply Shannon's theorem to three-dimensional functions of directivity to find the optimal density of microphone positions, [2] . But it seems one needs a certain amount of knowledge on the radiation pattern of the source in advance, and possibly more than that is required by the standards [3] or in other proposals concerning “hot spots“ as in [4]. So why not try another assumption, e.g. the assumption that all measured level values are strictly dependent following a given distribution?

Theoretical Approach

There might be a partial measurement surface consisting of a 1 m wide strip of a larger parallelepiped. On that strip a few different level distributions according to Figure 1 may be assumed.

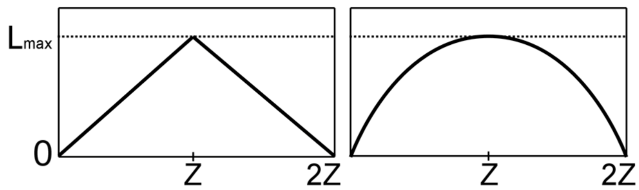

Figure 1: Two level distributions along a partial measurement surface strip with length 2Z, left according equation (1), right according equation (2).

The left part of the first one may follow the equation

$$L = \mathrm{L}_{\max} \times x \qquad (1)$$

with $x = z/Z$ and the length of the strip of 2Z.

The left part of the second distribution can be described by

$$L = 10\,\mathrm{lg}(1 + (10^{0.1\mathrm{Lmax}} - 1)\sin\frac{\pi}{2}x) \qquad (2)$$

With x = z/Z .

This second distribution seems rather similar to real radiation patterns. A different number of microphone positions related to equal areas of the strip surface might be chosen to calculate the energetic average to be compared with the exact value which is given e.g. by the integral

$$\overline{L_{\mathrm{int}}} = 10\,\mathrm{lg}\Big(\int_{x=0}^{x=1} (10^{0.1\mathrm{L}_{\max}\times x})\ dx\Big) \qquad (3)$$

$$= 10\,\mathrm{lg}\left[\frac{10^{(0.1\mathrm{L}_{\max})x}}{0.1\mathrm{L}_{\max}\ \ln 10}\right]_0^1$$

The integral for distribution (2) is defined by

$$\overline{L_{\mathrm{int}}} = 10\,\mathrm{lg}\Big(\int_{x=0}^{x=1} (1 + (10^{0.1\mathrm{L}_{\max}} - 1)\sin\frac{\pi}{2}x)dx\Big) \qquad (4)$$

$$= 10 \cdot \mathrm{lg}\left[x - \frac{2}{\pi}(10^{0.1\mathrm{L}_{\max}} - 1) \cdot \cos(\frac{\pi}{2}x)\right]_0^1$$

Some Results

Results of the above mentioned comparison are shown in figures 2 and 3 for both distributions used and depending on the number of microphone positions for different $\mathrm{L}_{\max}$ as parameter with the steps 5, 10, 15 and 20 dB following

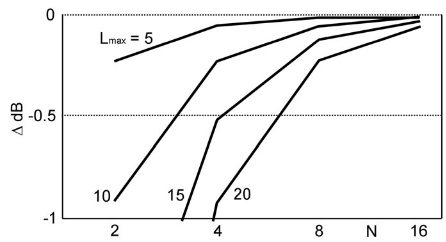

Figure 2: Deviations $\Delta = \overline{L_{calc}} - \overline{L_{\mathrm{int}}}$ of the average level from the integral value determined with the exact values on different numbers N of measurement positions for the triangle distribution according equation (1), $\mathrm{L}_{\max}$ as parameter .

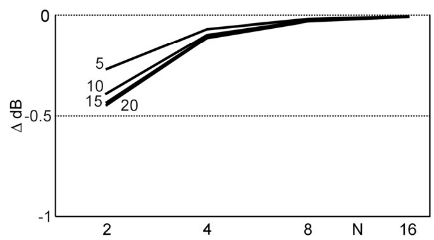

Figure 3: Deviations $\Delta = \overline{L_{calc}} - \overline{L_{\mathrm{int}}}$ of the average level from the integral value determined with the exact values on different numbers N of measurement positions for the sine distribution according equation (2), $\mathrm{L}_{\max}$ as parameter.

experiences at directional sources. The highest value can occur e.g. at an enclosure with a single radiating opening. The deviations Δ in figures 2 and 3 show a distinct difference between both the distributions. This difference might be explained using the nomenclature of [2]. There Shannon's theorem has been adopted to directivity functions by defining a contour spectrum and the appropriate spacious sampling rate, which should more than double the highest frequency component of this spectrum. Among signals the triangle needs a higher sampling rate than a sine signal, but contrary to the signal domain where a correct detection of the signal shape has priority one needs only the partial sound power of an existing directivity function. The number of measuring positions might be further reduced taking other errors into account.

Other Errors

The deviations Δ seem to be fairly small, but that is not surprising: all random errors are missing yet. In real situations and following the "Guide to the expression of uncertainty in measurement"(GUM) one has to look for the uncertainty component with the highest relevance for the combined uncertainty. In this "floating system" of GUM according to [1] the number of measurement positions might be reduced if e.g. the changing operating conditions of the source lead to the highest contribution to the combined uncertainty. Here random errors were applied using respective investigations of the uncertainty, starting with the

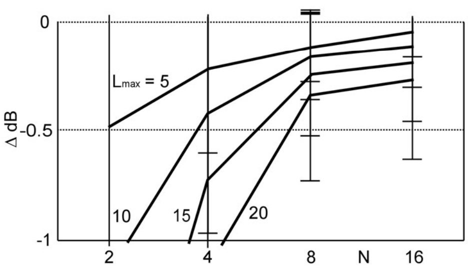

Figure 4: Deviations $\Delta = \overline{L_{calc,rd}} - \overline{L_{\text{int}}}$ of the average level from the integral value determined with random error added values on different numbers N of measurement positions for the triangle distribution according equation (1), with standard deviations of the mean values, standard deviation of repeatability of the single sound pressure level s_r=0.7 dB.

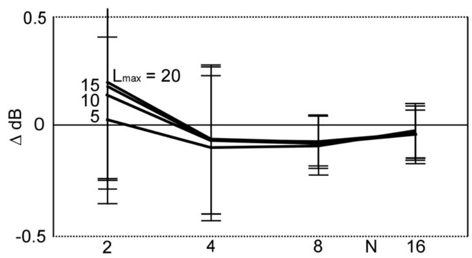

Figure 5: Deviations $\Delta = \overline{L_{calc,rd}} - \overline{L_{\text{int}}}$ of the average level from the integral value determined with random error added values on different numbers N of measurement positions for the sine distribution according equation (2), with standard deviations of the mean values, standard deviation of repeatability of the single sound pressure level s_r=0.7 dB.

uncertainty of 0.3 dB as in [5] according GUM and the standard deviation of repeatability of 0.5 dB for woodworking machinery [6] followed by the results of a round robin with 0.7 dB [7]. The latter two values include random errors generated by changing operating conditions. With these parameters normal distribution weighted random errors are then added to the exact values on the different positions. In each set of measuring positions the random errors have been generated five times anew. The results, see figures 4 and 5, confirm generally the advantages of the "floating system" as mentioned above. Otherwise the obvious interdependence between different level distributions and the deviations Δ leads to the question what must be known before starting a measurement.

Hot Spot

Considering reflections in ordinary rooms as allowed in [3] it seems that all regions of a sound field with interdependent levels or not heavily affected by the reflections are hot spots which need a minimum number of measurement positions. In the other regions statistical methods may be applied or a minimum density of positions given by the standard. It seems the rules for adding measurement positions according to [3], i.e. mainly the decision related to the number of positions initially chosen and compared with the maximum level difference is not appropriate considering Shannon's theorem. The use of a formal measure of directivity may be also misleading in cases of machinery with more than one partial sound source. Applying different densities of measurement positions needs more than the definition of the machine as a black box, it needs a certain knowledge of the radiation pattern in advance. If not achievable by a layman the standards body for the specific machine group may investigate its average radiation properties and give advice in the specific standard. To prepare a practicable rule for usual measurement surfaces needs further investigations.

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