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CONSIDERATIONS ON THE VERIFICATION OF DECLARED NOISE EMISSION VALUES

A. Schaffner

AUVA, Adalbert-Stifter-Str. 65, 1200, Vienna, Austria

Tel.: +43-1-33111-518 / Fax: +43-1-33111-621 / Email: albert.schaffner@auva.sozvers.at

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ABSTRACT
As the determination of the sound power level L_W of a sound source is always subject to random disturbances L_W may be regarded as a random variable. Therefore the comparison of different measurements (maybe according to different standards) is only possible based on statistical analysis. The problem is to decide whether two (or more) measurement results have to be accepted as equal on a given confidence level.

1 - INTRODUCTION
Assume the following practical situation. A manufacturer performs a sound power measurement according to standard A in order to correctly label the sound source. If the customer wants to verify the labelled value he will perform a second measurement according to standard B which does not have to be identical with standard A.
ISO 7574/1 [1] suggests that if the result obtained by the customer, i.e. L_B, is smaller than or equal to the labelled value compliance is given. If L_B is larger the labelled value is not confirmed. ISO 7574/1 does not provide any rules how to proceed in the second case.
In practice the sound power of the source will be determined by an expert for a third time (measurement C) and the result will again be tested against the labelled value.
This complete confirmation process is analyzed in the following.

2 - DISTRIBUTION OF THE DIFFERENCE BETWEEN TWO SOUND POWER MEASUREMENT RESULTS
If the distribution for the sound power level L_A measured according to standard A is a normal distribution $N\left(\mu_A, \sigma_A^2\right)$ and the distribution for the sound power level L_B measured according to standard B is a normal distribution $N\left(\mu_B, \sigma_B^2\right)$, the difference $L_B - L_A$ is normally distributed by $N\left(\mu_B - \mu_A, \sigma_A^2 + \sigma_B^2\right)$ [2].
The difference $L_B - L_A$ again is a random variable L_{BA} with an estimated mean $\mu_{BA} = \mu_B - \mu_A$ and variance $\sigma_{BA}^2 = \sigma_A^2 + \sigma_B^2$. If the two measurement procedures are unbiased μ_{BA} equals zero.
In practice it is important to consider biased measurements, which include either a systematic error in a measurement procedure or a systematic error in the labelling of the source. Performing control measurements one wants to find out these systematic differences.
Assume that the measurement A is biased i.e. the mean μ_A of the distribution $N\left(\mu_A, \sigma_A^2\right)$ is smaller than the mean μ_B. The null hypothesis of the measurement B is that the result A is correct. As long as $L_{BA} \leq \mu_{BA} + L_{BA\ max}$ - where

$$L_{BAmax} = 1.645 \cdot \sigma_{BA} \quad (1)$$

assuming a confidence level of 95% − the null hypothesis will not be rejected, which is the wrong conclusion. The probability of failing to reject the null hypothesis when it is false can be illustrated by the operating characteristic curve.

3 - OC-CURVE FOR THE DIFFERENCE L_{BA}

The distribution of L_{BA} is a normal distribution $N\left(\mu_{BA}, \sigma_{BA}^2\right)$ with density

$$f\left(l_{BA}\right) = \frac{1}{\sqrt{2\pi} \cdot \sigma_{BA}} \cdot e^{-\frac{1}{2} \cdot \left(\frac{l_{BA} - \mu_{BA}}{\sigma_{BA}}\right)^2} \quad (2)$$

Assuming unbiased measurements, the maximum acceptable difference between the labelled value and the result of measurement B is given by $L_{BA\ max}$ (see equation 1).
The probability of accepting the null hypothesis is given by the integral

$$F_{BA} = \int_{-\infty}^{L_{BAmax}} f\left(\ l_{BA}\right)\ d\ \ l_{BA} \quad (3)$$

As in the case of biased measurements the mean of the distribution $N\left(\mu_{BA}, \sigma_{BA}^2\right)$ will be shifted to higher values – since the estimated difference between the measurements A and B will increase when μ_A decreases – and the probability for acceptance will become less.
The OC-curve for the difference L_{BA} is given in figure 1 for the standard deviation σ_B=1 dB (σ_A has been set to 1). It can be seen that for a bias of 2.3 dB the probability of accepting the labelled value is still 50 %.

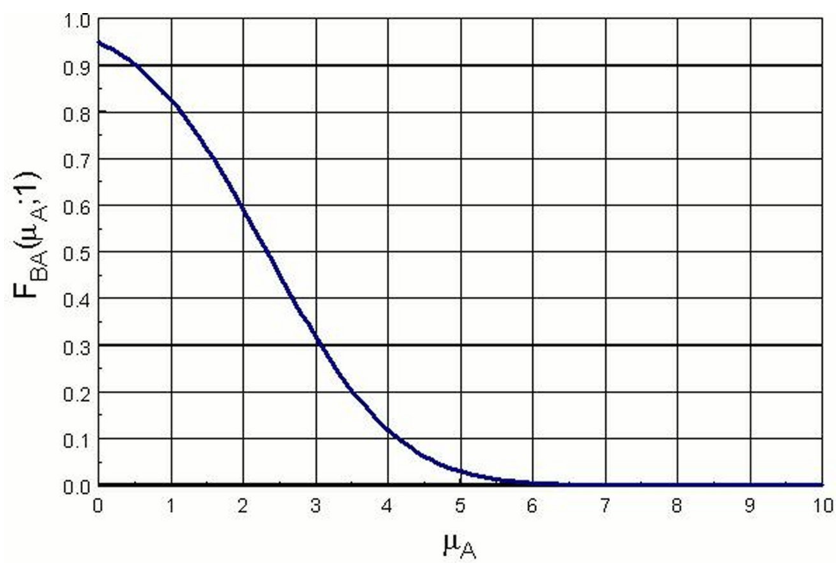

Figure 1: Probability of acceptance F_{BA} over bias μ_A for σ_B=1 dB.

4 - OC-CURVE FOR THE DIFFERENCE L_{CA}

The null hypothesis for this test is again that result A is correct. As long as $L_{CA} \leq \mu_{CA} + L_{CA\ max}$, the null hypothesis will not be rejected, which is the wrong conclusion.
The probability of accepting the null hypothesis is given by the integral

$$F_{CA} = \frac{1}{1 - F_{BA}} \int_{-\infty}^{L_{C\ A\ max}} f\left(\ l_{CA}, l_{BA} > L_{BA\ max}\right)\ d\ l_{CA} \quad (4)$$

The operating characteristic curves for different combinations of standard deviations of reproducibility have been plotted in figure 2.

5 - OC-CURVE FOR THE COMPLETE CONFIRMATION PROCESS

The probability F_{CBA} of accepting the null hypothesis (i.e. result A is correct) is given by

$$F_{CBA} = F_{BA} + (\ 1 - F_{BA}) \ \cdot \ \ F_{CA} = F_{BA} + F_{CA} - F_{BA}F_{CA} \quad (5)$$

As F_{CBA} is larger than F_{BA} the probability of accepting the null hypothesis increases with the additional measurement.
The operating characteristic curves for the complete confirmation process have been plotted in figure 3 for different combinations of standard deviations of reproducibility.

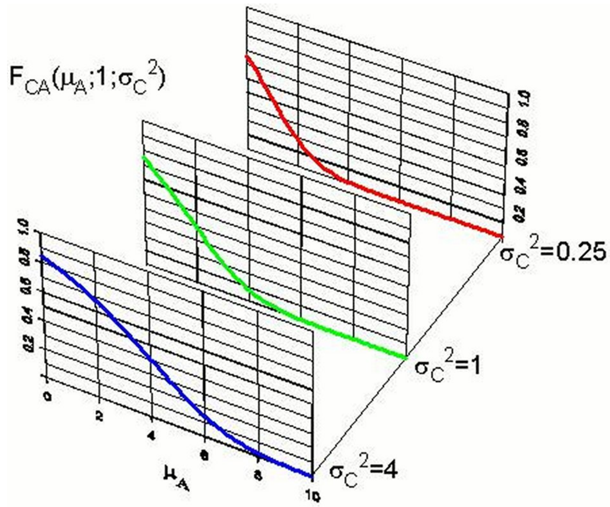

Figure 2: Probability of acceptance F_{CA} over bias μ_A: σ_B=1 dB, σ_C=0.5, 1, 2 dB.

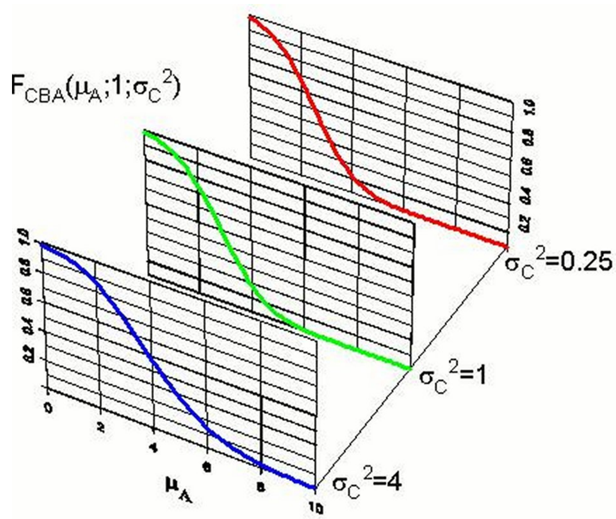

Figure 3: Probability of acceptance F_{CBA} over bias μ_A: σ_B=1 dB, σ_C=0.5, 1, 2 dB.

From these figures one can see that the confirmation process will be more sensitive when one uses standards with small values of the standard deviation of reproducibility. The probability of acceptance F_{CBA} depends on the combination of different standard deviations but not on the order in which the respective standards are used for the measurements B and C. It is obvious from equation 5 that F_{CBA} is invariant against an interchange of F_B and F_C.
Table 1 shows the bias values for 50% and 95% probability of acceptance F_{CBA} for different combinations of standard deviations.

	combination of standard deviations σ_B/σ_C		
$\mathbf{F_{CBA}}$	**0.5 dB / 0.5 dB**	**1 dB / 1 dB**	**2 dB / 2 dB**
50 %	2.1 dB	2.9 dB	4.8 dB
95 %	0.35 dB	0.74 dB	1.78 dB

Table 1: Bias values for a given probability of acceptance F_{CBA} and for different combinations of standard deviations.

The values given in table 1 show that a restriction on the allowed measurement procedures to standards of either precision (standard deviation of reproducibility of typically 0.5 dB for the A-weighted sound power level) or engineering grade (standard deviation of reproducibility of typically 1.5 dB for the A-weighted sound power level) would yield a reasonable high sensitivity of the compliance check for a confidence level of 95 % as a bias of 2 dB will be checked out.

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