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Emission sound pressure level and measurement uncertainty

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EN 71-1 Safety of toys – Part 1 Mechanical and physical properties is under revision with respect to noise. Part of this work includes round – robin measurements by 10 different laboratories in Europe and China on a number of selected toys and a loudspeaker reference sound source. The measurements have been carried out with the latest 2010-versions of the EN ISO 11200-series. The measurement uncertainty has been evaluated using both the modelling approach according to the ISO GUM and statistical methods applied on the measurement result as indicated in different standards. Comparing the results of the different methods to estimate the measurement uncertainty gives rise to several fundamental questions which will be discussed in the paper. One of these questions is the definition of repeatability and another one the meaningfulness of different equations in the uncertainty chapters of the latest standards.

1 Introduction

The 2010 versions of the emission sound pressure level standards in the ISO 11200-series include new requirements on the determination of the measurement uncertainty. A clear separation is made between uncertainty due to operating and mounting conditions and that of measurement procedure and measurement environment. It is also recommended to use the ISO GUM modelling approach whenever possible to estimate the uncertainty. In the following these recommended procedures have been followed and applied on a round-robin test involving 10 different laboratories in Europe and in China. The results give rise to some interesting questions.

Most laboratories taking part in the round-robin were equipped with hemi-anechoic rooms qualified according to EN ISO 3745 with a negligible environmental correction K_2. Some had slightly worse rooms but as all measurements took place at a distance of 0,5 m. EN ISO 11201, [1], was applied without any environmental corrections.

2 Measurement uncertainty

2.1 General

The uncertainty, $u(L_p)$, in decibels, associated with the emission sound pressure level determined in accordance with the 2010 version of EN ISO 11201 is estimated by the total standard deviation, σ_{tot}, in decibels:

$$u(L_p) \approx \sigma_{tot} \qquad (1)$$

This total standard deviation is preferably obtained using the modelling approach described in ISO/IEC Guide 98-3. This requires a mathematical model, which in the case of lack of knowledge can be replaced by results from measurements, including results from round robin tests. In this context, this standard deviation is expressed by the standard deviation of reproducibility of the method, σ_{R0}, in decibels, and the standard deviation, σ_{omc}, in decibels, describing the uncertainty due to the variability in operating and mounting conditions and instability of the source under test.

The total standard deviation, is given by

$$\sigma_{tot} = \sqrt{\sigma_{R0}^2 + \sigma_{omc}^2} \qquad (2)$$

σ_{R0} is either determined from round-robin measurements or using the modelling approach of GUM, [2].

2.2 Determination of σ_{R0} using round-robin tests

The round robin test for determining σ_{R0} shall be carried out in accordance with ISO 5725, where the emission sound pressure level of the source under test is determined under reproducibility conditions, i.e. different persons carrying out measurements at different testing locations with different measuring instruments. Such a test provides the total standard deviation, σ'_{tot}, relevant to the individual sound source which has been used for the round robin test. Participating laboratories in round robin tests should cover all possible practical situations. This total standard deviation, σ'_{tot}, in decibels, of all results obtained with a round robin test includes the standard deviation, σ'_{omc}, and allows σ'_{R0} to be determined by using

$$\sigma'_{R0} = \sqrt{\sigma'^2_{tot} - \sigma'^2_{omc}} \qquad (3)$$

As will be shown later this procedure, described in EN ISO 11201, is often difficult to implement as it often happens that $\sigma'_{omc} >> \sigma'_{R0}$, that is $\sigma'_{tot} \approx \sigma'_{omc}$.

2.3 Determination of σ_{R0} using the modelling approach

Generally, σ_{R0}, in decibels, is dependent upon several partial uncertainty components, $c_i u_i$, associated with the different measurement parameters such as uncertainties of instruments, environmental corrections, and microphone positions. If these contributions are assumed to be uncorrelated, σ_{R0} can be described by the modelling approach presented in ISO/IEC Guide 98-3, [2], as follows:

$$\sigma_{R0} = \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2 + ... + (c_n u_n)^2} \qquad (4)$$

In Equation (4), the uncertainty components due to the instability of the sound emission of the source are not included. These components are covered by σ_{omc}.

Preliminary estimations show that the general expression for the calculation of the final result of the emission sound pressure level measurement, including all corrections prescribed by EN ISO 11201 with all relevant uncertainties, L_p, is given by

$$L_p = L_p(L'_p, \delta(B), \delta_{env}, \delta_{slm}, \delta_{mount}, \delta_{oc}, \delta_{pos}, \delta_{met}) \qquad (5)$$

where

L'_p is the measured (uncorrected) sound pressure level;

$\delta(B)$ is an input quantity to allow for any uncertainty on background noise corrections;

δ_{env} is an input quantity to allow for any uncertainty due to the local environmental influence;

δ_{slm} is an input quantity to allow for any uncertainty in the measuring instrumentation;

δ_{mount} is an input quantity to allow for any variability in the mounting conditions of the source under test;

δ_{oc} is an input quantity to allow for any deviation in the operating conditions of the source under test from the nominal conditions;

δ_{pos} is an input quantity to allow for any uncertainty in selection of the measuring position;

δ_{met} is an input quantity to allow for any uncertainty in determining the meteorological conditions.

Table 1: Calculation according to the modelling approach

Quantity	Estimate	Standard uncertainty, u_i	Sensitivity coefficient, c_i	Uncertainty contribution $c_i^2 u_i^2$
L_p				
L'_p	L'_p	0,5	$\dfrac{1}{1-10^{-0,1\left[L'_p - L_{p(B)}\right]}}$ 1,1 (ΔL=10)	0,31
$\delta_{(B)}$	K_1	$\sqrt{0,5^2 + 0,5^2}$	$\dfrac{1}{1-10^{0,1\Delta L}}$ -0,1 (ΔL=10)	0,01
δ_{env}	0 K_3 0	0 – 1 (ISO 11201) 0,5 K_3(ISO 11202) ?? (ISO 11202, L_{pCpeak})	1 1 1	0,0 (ISO 3745 room) 0,25 K_3^2
δ_{slm}		See L'_p		
δ_{pos}		0,2	1	0,04
δ_{met}		0,3	1	0,09

Adding up the values in table 1 we get for a hemi-anechoic room according to ISO 3745:

$$\sigma_{R0} = \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2 + ... + (c_n u_n)^2} = \sqrt{0,45} = 0,7 dB \qquad (6)$$

3 Some measurement results

3.1 Standard deviation of reproducibility of the test method, σ_{R0}

Figure 1. The refence source on the floor and in a stand 1,2 m above the floor respectively

As reference sound source (RSS) a loudspeaker fed by an ipod with prerecorded sound was used. The RSS was measured both in a position on the floor and mounted in a stand 1,2 m above the floor. The microphone positions were specified 50 cm from the loudspeaker. The repeatability of the RSS, here denoted σ'_{omc} was tested by the peer review laboratory which had designed the RSS and recorded the signals. The results are given in Table 2 and 3 for the floor mounted and the stand mounted RSS respectively.

Table 2 Floor mounted source

	True	σ'_{omc}	σ'_{tot}	σ'_{R0}
LAeq	87,1	0,1	0,5	0,5
LpCpeak1	109,3	0,1	0,5	0,5
LpCpeak2	107,7	0,4	0,6	0,5

Table 3 Stand mounted source

	True	σ'_{omc}	σ'_{tot}	σ'_{R0}
LAeq	87,4	0,1	0,6	0,6
LpCpeak1	107,6	0,1	0,7	0,7
LpCpeak2	107,3	0,2	0,9	0,9

σ'_{tot} is the total standard deviation from the measurements from the 10 different laboratories (excluding single outliers due to erroneous handling of the RSS). Thus the reproducibility calculated from the measurements becomes

$$\sigma'_{R0} = \sqrt{\sigma'^2_{tot} - \sigma'^2_{omc}} \qquad (7)$$

This value can be compared with the value calculated according to Table 1 and given in eq.(6) using the modelling approach which was 0,7 dB which is in good agreement with the tabulated values in table 2 and 3 which range from 0,5 to 0,9 dB.

3.2 Standard deviation of operating and mounting conditions σ_{omc}

The ISO-standards point at eq. (7) as a means to calculate σ'_{R0}. However, for toys, it turns out that that $\sigma'_{omc} \approx \sigma'_{tot}$. This means that eq. (7) cannot be used with a reasonable accuracy. Instead we have to use the equation

$$\sigma'_{omc} = \sqrt{\sigma'^2_{tot} - \sigma'^2_{R0}} \qquad (8)$$

where we get σ'_{R0} from the modelling approach and σ'_{tot} from the round-robin measurements.

In figure 2 the results from the round-robin measurements on 11 toys by 10 different laboratories are shown. One outlier with σ'_{omc} exceeding 10 dB has been excluded. The mean values and the standard deviations are given in table 4.

Table 4 Statistics of figure 2

	Mean	s
LAeq	2,3	0,9
LpCpeak	2,0	0,9

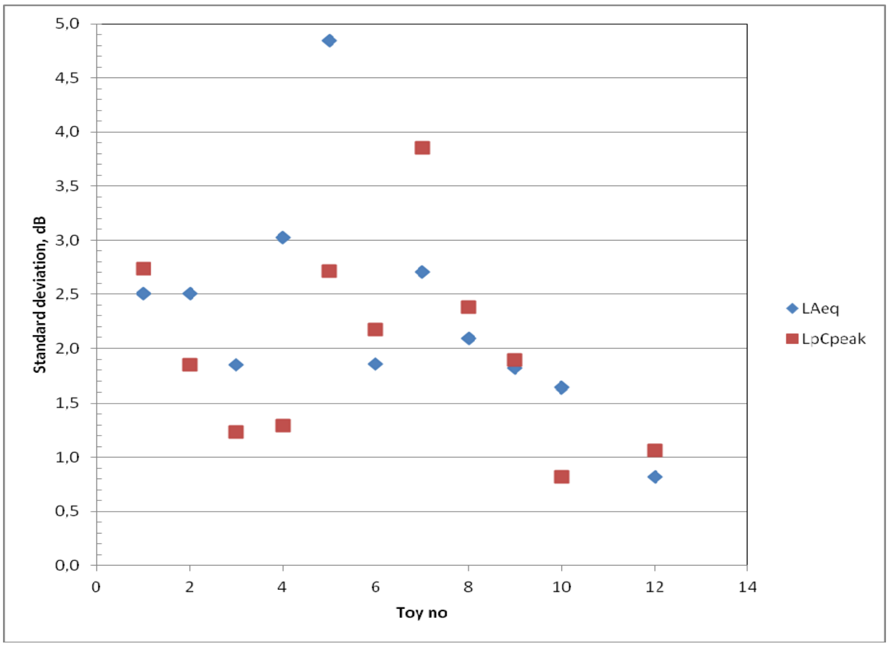

Figure 2 Round-robin reproducibility standard deviation due to operating and mounting conditions

Figure 2 and table 2 refer to a kind of mixture of repeatability and reproducibility. The standard, on the other hand, specifies that each laboratory is to determine the repeatability of the operating conditions by repeating the measurements preferably 5 times. This was also made for the round robin measurements and the results are shown in Figure 3 and 4 together with the results of Figure 2. For toys no 4, 5, 6, 7, 8, 9 and 12 the repeatability within in the laboratories is the standard deviation of 3 different operators of hand actuated toys whereas the other toys were measured several times with the same operator.

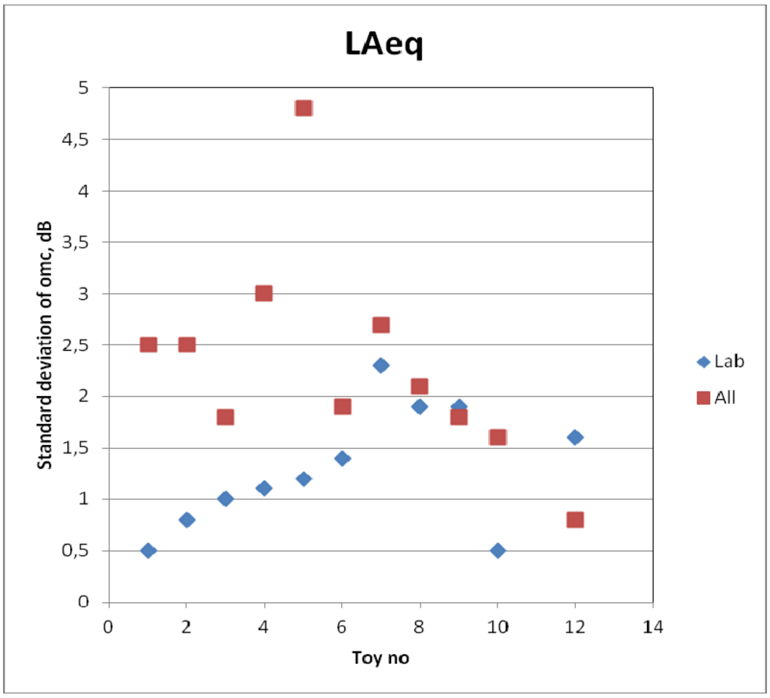

Figure 3 Comparison between internal repeatability (Lab) and reproducibility repeatability (All)

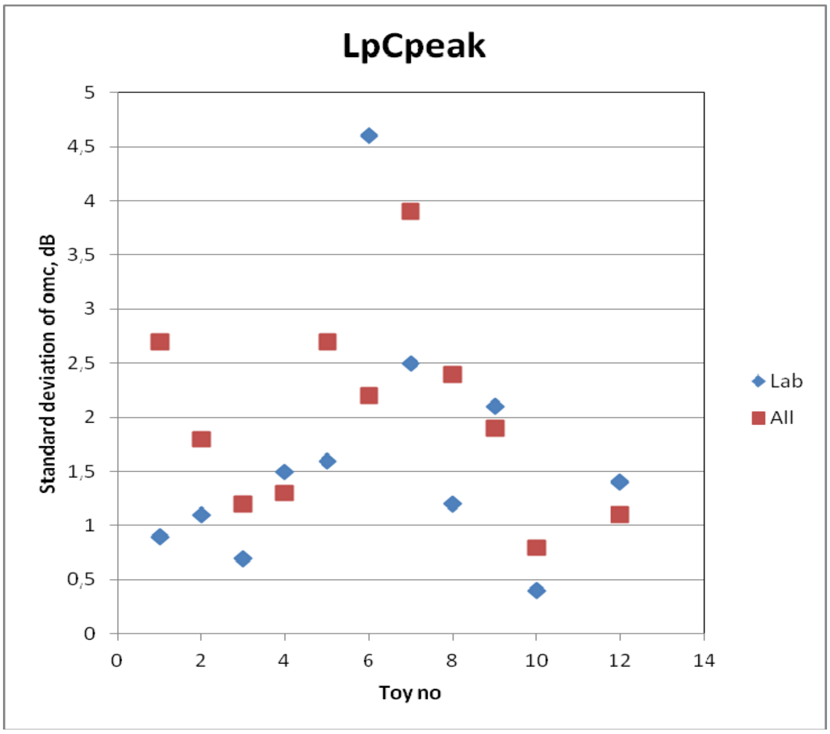

Figure 4 Comparison between internal repeatability (Lab) and reproducibility repeatability (All)

Figure 3 and Figure 4 clearly indicate that the difference between the internal repeatability and the one between different laboratories may be substantial.

4 Discussion and conclusions

For measurements of emission sound pressure levels according to EN ISO 11201 the modelling approach of ISO GUM works well to determine σ_{R0}. Round-robin measurements are not likely to yield reliable results unless the sound sources to be tested are extremely stable and insensitive to changes in mounting and operating conditions.

The concept of σ_{omc} as defined in the present standards is questionable as it only reflects the internal repeatability which may be very different from the "real" repeatability obtained when repeating operating and mounting conditions at different laboratories. In fact there seems to be a need to introduce a new definition of a kind of "reproducibility repeatability".

A problem with the reproducibility repeatability is that it cannot be determined by the individual laboratory. It can only be determined in a round-robin and even then it will depend on the sources tested. In this paper toys have been used as an example and they show up large variations. The reproducibility repeatability in the example was in the range 1-4 dB. In order to be able to use this information in practical cases it will be necessary to classify each toy in a certain uncertainty class and that may not be so easy.

5 Acknowledgement

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References

[1] EN ISO 11201:2010 Acoustics — Noise emitted by machinery and equipment — Determination of emission sound pressure levels at a work station and at other specified positions in an essentially free field over a reflecting plane with negligible environmental correctionsK. Maxim, Noise Problems in schools, *Journal of noise*, 111, 2005, 1111–1122.

[2] ISO/IEC Guide 98-3:2008, Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)