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CALCULUS OF THE UNCERTAINTY IN ACOUSTIC FIELD MEASUREMENTS: COMPARATIVE STUDY BETWEEN THE UNCERTAINTY PROPAGATION METHOD AND THE DISTRIBUTION PROPAGATION METHOD

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Abstract

The new Spanish Regulation in Building Acoustic establishes values and limits for the different acoustic magnitudes whose fulfillment can be verify by means field measurements. In this sense, an essential aspect of a field measurement is to give the measured magnitude and the uncertainty associated to such a magnitude. In the calculus of the uncertainty it is very usual to follow the uncertainty propagation method as described in the Guide to the expression of Uncertainty in Measurements (GUM). Other option is the numerical calculus based on the distribution propagation method by means of Monte Carlo simulation. In fact, at this stage, it is possible to find several publications developing this last method by using different software programs. In the present work, we used Excel for the Monte Carlo simulation for the calculus of the uncertainty associated to the different magnitudes derived from the field measurements following ISO 140-4, 140-5 and 140-7. We compare the results with the ones obtained by the uncertainty propagation method. Although both methods give similar values, some small differences have been observed. Some arguments to explain such differences are the asymmetry of the probability distributions associated to the entry magnitudes, the overestimation of the uncertainty following the GUM…

Keywords: uncertainty, testing laboratory, laboratory accreditation

1 Introduction

The objective of a measurement is to assign a magnitude to the measurand, the quantity intended to be measured. The assigned magnitude is considered to be the best estimate of the values of the measurand. The uncertainty evaluation process will encompass a number of influences quantities that affect the result obtained for the measurand. Consequently the result of a measurement is only an approximation to the value of the measurand and is only complete when it is accompanied of the uncertainty. In order to quantify the uncertainty we will have to consider all the factors that could influence the results. The Guide to the Expression of Uncertainty in Measurement, GUM [1], published by the International Organization for Standardization provides an analytical methodology on the evaluation and reporting of measurement uncertainty that can be applied in most fields of physics measurements. Monte Carlo simulation is an alternative approach to uncertainty evaluation in which the propagation of uncertainties is undertaken numerically rather than analytically [2]. This technique is able to provide much richer information by propagating the distributions rather that just the uncertainties.

Concerning acoustic field measurements, the new Spanish Regulation in Building Acoustics (CTE DB HR, Documento Básico de Protección frente al Ruido [3]) contains the necessity of controlling the noise levels in the buildings. This document establishes a set of criteria for the acoustic performance of the buildings in order to fulfill acoustic comfort conditions indoors. In general, all these criteria are expressed in terms of permissible minimum values for the airborne and façade sound insulating parameters and permissible maximum values for the impact sound insulating parameters. Other interesting novelty of the new regulation is the possibility to verify the fulfillment of the established criteria by means of field measurements. In particular, the field measurements of airbone sound insulation between rooms must be made according to ISO 140-4 [4] and the standardized level difference, D_{nT}, and the sound reduction index R´ are the insulation parameters that must be evaluated. The field measurements of impact sound insulation must be made according to ISO 140-7 [5] and L'_{nT} is the parameter that must be calculated, the façade sound insulation must be according to ISO 140-5 [6] and $D_{2m,nT}$ is the parameter associated. In this same line, the single-number magnitudes associated to these field measurements are ($D_{nT,w}$ + C) in the case of ISO 140-4, and L'_{nTw} and ($D_{2m,nTw}$ + C_{tr}) are the single-number parameters related to ISO 140-7 and ISO 140-5 respectively [7,8] .

A fundamental aspect in the field of evaluations for the fulfillment of the Spanish Regulation is that any parameter calculated must included an uncertainty factor related to the experimental measurement uncertainty. The uncertainty can affect compliance with the specification limit. On the other hand, it is usual that some autonomic legislation in noise matter is asking to the laboratories to have an accreditation as a testing laboratory. To get the accreditation the laboratory has to define a quality management system following the requirements contained in standard ISO/IEC 17025 [9]. Among the requirements, this standard demands to the laboratory to demonstrate that they are technically competent and are able to generate technically valid results defining a clear routine for the calculus of the experimental measurement uncertainty.

In the present work, we estimate the uncertainty of acoustic parameters calculated in real field measurements performed by the "Laboratorio de Acústica y Vibraciones de la Escuela Técnica Superior de Arquitectura de la UPM" according to ISO 140-4, 140-5 and 140-7. We present a comparative study between uncertainties calculated using the general method of propagation of uncertainties and distributions propagation method using Monte Carlo simulation. Both methods give reasonable results, however higher values of the uncertainties in practically all the frequency range have been calculated in the case of the uncertainties propagation method. We analyze these differences and discuss the advantages and disadvantages of both methods. For the numerical Monte Carlo simulation the Excel software has been used. The easy operation of this software could convert the Excel in an attractive option for the usual calculus of uncertainties in testing laboratories.

2 Methods used for the calculus of uncertainties

2.1 Uncertainties propagation method: GUM

The result is an estimate of the mesurand y calculated as a function of the estimates of the input quantities. The first step in evaluating the measurement uncertainty is to specify the mesurand and its relation with the input quantities $(X_1,.........,X_n)$. The next step is to list the estimates $(x_1,.........,x_n)$ of the input quantities and the possible sources of uncertainty, quantifying the uncertainty components. Components of uncertainty are evaluated by the appropriate methods (as described below) and each is expressed as a standard deviation and is referred to as a standard uncertainty $u(X_i)$. However, each input quantities can affect the measurand in a different way. To describe how sensitive the result is to a particular quantity, the sensitivity coefficient c_i associated which each input variable is defined. The sensitivity coefficient is the partial derivative of the model function f with respect to X_i evaluated at the input quantities. One the standard uncertainties and the sensitivity coefficients have been calculated, the standard uncertainty components are combined to produce an overall value of uncertainty, known as the combined standard uncertainty. The combined standard uncertainty is calculated as follows:

$$u_C(y) = \sqrt{\sum_{i=1}^{N} c_i^2 u^2(X_i)}$$

The GUM recognizes the need for providing a high level of confidence associated with an uncertainty and uses the expanded uncertainty, which is obtained by multiplying the combined standard uncertainty by a coverage factor, $U = ku_C(y)$. In accordance with generally accepted international practice, it is recommended that a coverage factor of $k = 2$ is used to calculate the expanded uncertainty. This value of k will gives a coverage probability of approximately 95 %.

The uncertainty of a measurement generally consists of several components that may be grouped into two categories according to the method used to estimate their numerical values. ”Type A” evaluation of standard uncertainty is done by calculation from a series of repeated observations using statistical methods. Type B evaluation of standard uncertainty is done by means of other than used for “Type A”. For example, based on data in calibration certificates, previous measurement data, experience with the behavior of the instruments, manufacturers´ specifications and all other relevant information.

2.2 Probabilities propagation method by Monte Carlo simulation

This method is numerical and in agreement with the GUM principles. The contribution of uncertainty from each input variable is characterized as a probability distribution, so as a range of possible values with information about the most likely value of the input quantity. The probability distribution is a reflect of the available knowledge about the particular quantity. If in a set of readings the values are more likely to fall near the average than further away, it is a typical normal or Gaussian distribution. When the measurements are quite evenly spread between the highest and the lowest values, a rectangular or uniform distribution is produced. More rarely, distributions can have other shapes, for example, triangular. Using the probabilities distribution in the Monte Carlo simulation the underlying system is run over and over again, each time using a different set of random numbers representing the input variables. Each of these sets of random numbers combines via the model to represent a different output. If the model is a good representation of the real system, then, by running a large enough number of simulations, the whole range of possible outputs can be produced, these values form the distribution of the output.

When a number of distributions of whatever form are combined, it can be shown that, apart from in exceptional cases, the resulting probability distribution tends to the normal form in accordance with the Central Limit Theorem [10]. In fact, if the dominant contribution is itself normal in form, clearly the resulting distribution will also be normal. Once the normal distribution for the output magnitude is obtained, its average value is the best estimation of such magnitude and the uncertainty is described in terms of its standard deviation. Different software as Mat lab, SAS, Excel, have implemented the convenient techniques depending on the kind of variable and distribution to perform the Monte Carlo simulation. In this work, for the facility of use and presentation, Excel has been the software chosen for the Monte Carlo simulation.

3 Results and Discussion

3.1 Field measurements

For the study, data from some field measurements performed by the “Laboratorio de Acústica y Vibraciones de la UPM” according to ISO 140-4, 140-5 and 140-7 have been chosen. The following expressions have been used for the calculus of the parameters derived depending on the field measurement [11]:

UNE EN ISO 140-4:

$$D_{nT} = (L_1 + \delta(L_1)) - (L_2 + \delta(L_2)) + 10\log\left(\frac{T}{T_0}\right) \quad (1)$$

$$R' = (L_1 + \delta(L_1)) - (L_2 + \delta(L_2)) + 10\log\left(\frac{S \cdot T}{0{,}16 \cdot V}\right) \quad (2)$$

UNE EN ISO 140-5:

$$D_{2m,nT} = (L_1 + \delta(L_1)) - (L_2 + \delta(L_2)) + 10\log\left(\frac{T}{T_0}\right) \quad (3)$$

UNE EN ISO 140-7:

$$L'_{nT} = (L_2 + \delta(L_2)) - 10\log\left(\frac{T}{T_0}\right) \quad (4)$$

where L_1 and L_2 are the average pressure levels at the source and receiver room respectively, T is the reverberation time, V is the volume of the receiver room and S represents the common surface between receiver and source rooms. The terms $\delta(L_1)$ or $\delta(L_2)$ are used to represent the corrections associated to factors as equipment characteristics and environmental conditions that have to be considered in the final value of the average pressure levels. These corrections and the associated uncertainties will be described in detail in the next section. Nevertheless, one of the most important contributions to the pressure and reverberation time uncertainty is the associated to the repeatability of the number of measurements performed. In our case, we estimated the mean value and the standard deviation using the real values that we have measured. The standard deviation or uncertainty of the mean is then obtained by dividing such values by the square root of the number of measurements that contributed to the mean value.

3.2 Uncertainty components in the acoustic measurements

Careful consideration of each aspect involved in the field measurement is required to identify and list all the factors that contribute to the overall uncertainty. This is a very important step and requires good understanding of the measuring equipment, the principles and practice of the field measurement and the influence of environment. Concerning the environmental effects, the most commonly encountered when considering measurement uncertainty are temperature, relative humidity and barometric pressure. In Tables I and II we have summarized the meaningful corrections and uncertainties involved in expressions from (1) to (4) and that we have used for the calculation process. In Table I we have shown the ones associated to L_1 and L_2 input variables and the one associated to the variable T in Table II. The uncertainties associated to the environmental effects have been deduced from the microphone characteristics manual. We have considered as uncertainty the maximum variation that the environmental conditions can introduce in the lecture of the pressure level. The other correction and uncertainty values have been estimated based on data of the sound level calibration certificated. Normally, the sound pressure levels contribute more to the total uncertainty than the reverberation time, so their uncertainty components have been more carefully analyzed.

Uncertainty Contribution	**Distribution Type**	**Correction δ**	**Uncertainty (dB)**
Repeatability	Normal	0	$\frac{\sigma}{\sqrt{n}}$
Sound calibration of the sound level	Normal	0	(100-1000 Hz): 0,13 (1250-4000 Hz): 0,18 5000 Hz: 0,23
Resolution of the sound level display	Rectangular	0	0,029
Electrical calibration of the sound level	Rectangular	0	0,1
Linearity of the SLM in the range of reference	Normal	-0,004	0,0029
Ability of the rms detector to provide a true rms value	Normal	0,0091	0,0091
Correction due to the time weighting	Normal	-0,1	0,058
Effect of the temperature	Rectangular	0	0,17
Variations in the atmospheric pressure	Rectangular	0	0,23
Effect of the humidity	Rectangular	0	0,15

Table I. Corrections and uncertainties associated to L_1 and L_2.

Uncertainty Contribution	**Distribution Type**	**Correction δ**	**Uncertainty (s)**
Repeatability	Normal	0	$\frac{\sigma}{\sqrt{n}}$
Resolution of the sound level display	Rectangular	0	0,01 s

Table II. Corrections and uncertainties associated to T.

3.3 Units for the calculus of the uncertainty

Concerning the units, some authors suggest that it is more adequate to treat the input variables and associated uncertainties in linear scale rather than in dB [11, 12]. The final combined uncertainty is calculated in natural units, for example, as percentage (%) and then converted into dB. In order to analyze the variation of the final value depending on the units we have calculated the combined uncertainty working in both ways: a) working in dB directly and 2) expressing all the uncertainties in percentage and then converted them to dB at the end of the calculus. According the works presented by these authors, the following expressions could be used for the conversion to percentage and vice versa:

- from dB to a %: $u(\%) = 100 \cdot (10^{u(dB)/20} - 1)$
- from % to dB: $u(dB) = 20 \cdot \log(1 + \frac{u(\%)}{100})$

In the case the uncertainties are already expressed in lineal units, as for example the associated to T and to the environmental effects, the following expression has been used to express them in percentage:

$$u(\%) = 100 \cdot \frac{u(dB)}{ValorMagnitud}$$

In Table III and IV we have shown the combined uncertainty values as function of frequency for $D_{2m,nT}$ (ISO 140-5) and L'_{nT} (ISO 140-7) respectively. In these examples, the combined uncertainty has been calculated following the uncertainties propagation method described by the GUM.

Frequency (Hz)	**$u_C(D_{2m,nT})$** (directly in dB)	**$u_C(D_{2m,nT})$** (dB→%→dB)	**Difference**
100	2,15	2,11	0,04
125	0,94	0,87	0,07
165	1,29	1,26	0,03
200	1,45	1,42	0,03
250	1,26	1,23	0,03
315	0,85	0,81	0,04
400	0,94	0,92	0,02
500	0,77	0,74	0,03
630	0,75	0,72	0,03
800	0,71	0,69	0,02
1000	0,72	0,70	0,02
1250	0,70	0,68	0,02
1600	0,62	0,61	0,02
2000	0,66	0,64	0,02
2500	0,61	0,60	0,02
3150	0,58	0,56	0,02
4000	0,75	0,74	0,02
5000	0,65	0,63	0,02

Table III. Combined uncertainty of $D_{2m,nT}$ calculated working in dB directly (first column), working in percentage and converting to dB at the end of the calculus (second column) and differences (third column) between both ways of calculus.

Frequency (Hz)	u_C(L´nT) (directly in dB)	u_C(L´nT) (dB→%→dB)	Difference
100	1,88	1,86	0,02
125	0,86	0,81	0,06
165	1,16	1,09	0,08
200	0,87	0,83	0,03
250	1,21	1,19	0,02
315	1,84	1,81	0,02
400	1,29	1,27	0,02
500	0,87	0,86	0,02
630	1,29	1,27	0,02
800	0,88	0,87	0,01
1000	0,61	0,59	0,01
1250	1,31	1,30	0,01
1600	0,77	0,76	0,01
2000	0,65	0,64	0,01
2500	1,21	1,19	0,02
3150	1,47	1,45	0,01
4000	1,50	1,49	0,01
5000	1,83	1,82	0,01

Table IV. Combined uncertainty of L'_{nT} calculated working in dB directly (first column), working in percentage and converting to dB at the end of the calculus (second column) and differences (third column) between both ways of calculus.

Taking into account the values presented in previous tables, we consider that the differences are not significant compared to the absolute value of the combined uncertainty. That is usual when there is not a big dispersion between the field values measured. In any case, it is important to know that these differences can exist and in special cases as complicated room geometries, existence of dominant modes… it would be very adequate to confirm that they are not noteworthy. However, for uncertainty calculus routine in a field measurement laboratory we consider that working in natural units implement additional calculus and time without representing significative changes in the order of magnitude of the final combined uncertainty. So, taking into account the sound level gives the level pressures in dB in the following, the calculus we will be done directly in dB.

3.4 Number of simulations in Monte Carlo simulation

One important factor to be considered in Monte Carlo simulation is the number of repetitions or simulations of the process. In Table V we have presented the values of the final expanded uncertainty (using $k = 2$) associated to R´ (ISO 140-4) calculated using different numbers of simulations. The criterion is that the number of simulations must be enough to be sure that the results are not altered.

Above 1000 simulations the differences observed in the final values are not bigger than 0,1 dB, then in order to make faster the calculus process we consider that 1000 simulations could be adequate. It is important to indicate that other software programs can make the calculus faster than Excel. However, the advantage of the Excel software is the easy use, understanding of the commands and presentation of the final values on a template for the uncertainty calculus fabricated using this software.

	Number of simulations					
Frequency (Hz)	**1000**	**2000**	**4000**	**5000**	**12500**	**25000**
100	3,1	3,0	3,1	3,1	3,1	3,1
125	2,3	2,3	2,3	2,4	2,3	2,3
165	2,1	2,0	2,0	2,1	2,1	2,0
200	1,9	2,0	2,0	2,0	2,0	2,0
250	1,6	1,6	1,6	1,6	1,5	1,6
315	1,5	1,5	1,6	1,5	1,5	1,5
400	1,7	1,7	1,7	1,8	1,7	1,8
500	1,4	1,5	1,4	1,4	1,5	1,4
630	1,0	1,0	1,0	1,0	1,0	1,0
800	1,1	1,1	1,1	1,1	1,1	1,1
1000	1,1	1,1	1,0	1,0	1,1	1,0
1250	1,0	1,0	1,0	1,0	1,0	1,0
1600	1,0	0,9	1,0	0,9	0,9	0,9
2000	0,9	0,9	0,9	0,9	0,9	0,9
2500	1,0	1,0	1,0	1,0	1,0	1,0
3150	0,9	0,9	0,9	0,9	0,9	0,9
4000	0,9	0,9	0,9	0,9	0,9	0,9
5000	1,0	1,0	1,0	1,1	1,0	1,1

Table V. Expanded uncertainty of R´ calculated by means of the probability propagation method for different number of Monte Carlo simulations.

3.5 Comparison between probability propagation and uncertainties propagation methods

In Tables from VI to IX we have presented the values of the expanded uncertainty as a function of the frequency for all the parameters calculated in field measurements according to ISO 140-5, 140-4 and 140-7. The data correspond to some examples of field measurements performed by the "Laboratorio de Acústica y Vibraciones". In the Tables we have shown the values calculated by means of the distribution propagation method by Monte Carlo simulation (using 1000 repetitions), by means of uncertainties propagation method (working directly in dB) and in the third column we have included the difference between both methods. In general, the probability density function for the output magnitude in Monte Carlo simulation is not symmetrical, the parameter indicating the level of the asymmetry of the output distribution can also be calculated by Excel. Due to this possible asymmetry as the best estimation of the expanded uncertainty we have chosen the highest value among the difference between the mean value and cuantil (2,5), the difference between the mean value and cuantil (97,5) and the standard uncertainty of the probability distribution. The highest of these three values has been multiplied by a factor *2* in order to obtain the expanded uncertainty. This final value is the one we have presented in Tables VI to IX.

The values of the expanded uncertainty are identical by both methods of calculation in the case of L'_{nT} values evaluated according to ISO 140-7. In field measurements according to ISO 140-4 and 140-5, the values of the expanded uncertainties associated to the evaluated magnitudes are higher (with maximum difference values of 0,3-0,4 dB) when we calculate following the uncertainties propagation method. The asymmetry of the probability distribution function associated to the input magnitudes as the pressure levels could explain these differences. In general, this non-normality of the probability distribution is more appreciable at low frequency pressure levels. However, the differences between both methods in the D_{nT}, R´ and $D_{2m,nT}$ expanded uncertainty values are comparable in all the frequencies or even higher in the high frequency range. Then we believe that such a difference is more related to the particular expressions used for the calculus of D_{nT}, R´ and $D_{2m,nT}$. In expressions (1) to (3) the difference of pressure levels between source and receiver rooms appear, but not in expression (4). In Monte Carlo simulation we obtain possible values of levels pressure in source and receiver rooms derived from the real field measurement. These levels are subtracted for the calculus of the final value of D_{nT}, R´ or $D_{,2m,nT}$ and so some of the uncertainties and corrections associated to them. The collection of values generated in the simulation defines the width of the probability distribution of the output magnitude and so, its expanded uncertainty. We are always adding uncertainties in the case of uncertainties propagation method, so may be the expanded uncertainty is overestimated.

In any case, taking into account that the differences between these two methods are not higher than 0,5 dB, we believe that any of the two methods could be used in a testing laboratory to estimate the expanded uncertainties associated to the magnitudes derived from field measurements. However, the distribution propagation method based in Monte Carlo simulation gives richer information on the uncertainty because it is the repetition of the measurement by numerical simulation from the real field measurement values. Also this method provides us an easy calculus of the uncertainty associated to the single-number magnitudes as we have described in the next section.

Frequency	U Monte Carlo	U GUM	Difference
100	4,3	4,3	0,04
125	1,7	1,9	0,19
165	2,4	2,6	0,15
200	2,8	2,9	0,07
250	2,4	2,5	0,17
315	1,5	1,7	0,23
400	1,7	1,9	0,15
500	1,2	1,5	0,30
630	1,2	1,5	0,33
800	1,2	1,4	0,20
1000	1,2	1,4	0,24
1250	1,1	1,4	0,25
1600	0,9	1,2	0,33
2000	1,0	1,3	0,31
2500	0,9	1,2	0,31
3150	0,8	1,2	0,34
4000	1,3	1,5	0,24
5000	1,0	1,3	0,27

Table VI. Expanded uncertainty associated to $D_{,2m,nT}$ (ISO 140-5) calculated by means of the probability propagation method (first column) uncertainties propagation method (second column) and differences (third column) between both methods.

Frequency	U Monte Carlo	U GUM	Difference
100	2,9	3,3	0,34
125	2,3	2,5	0,21
165	2,1	2,2	0,11
200	2,0	2,1	0,13
250	1,6	1,8	0,17
315	1,4	1,8	0,32
400	1,8	1,9	0,13
500	1,4	1,7	0,30
630	1,0	1,3	0,37
800	1,1	1,4	0,28
1000	1,1	1,5	0,43
1250	1,0	1,3	0,34
1600	0,9	1,4	0,42
2000	0,8	1,3	0,37
2500	1,0	1,3	0,31
3150	0,9	1,2	0,36
4000	0,9	1,2	0,32
5000	1,0	1,4	0,31

Table VI. Expanded uncertainty associated to DnT (ISO 140-4) calculated by means of the probability propagation method (first column) uncertainties propagation method (second column) and differences (third column) between both methods.

Frequency	U Monte Carlo	U GUM	Difference
100	3,1	3,3	0,13
125	2,4	2,5	0,10
165	2,1	2,2	0,14
200	2,0	2,1	0,13
250	1,5	1,8	0,28
315	1,5	1,8	0,21
400	1,8	1,9	0,19
500	1,4	1,7	0,34
630	1,0	1,3	0,36
800	1,0	1,4	0,40
1000	1,0	1,5	0,48
1250	1,1	1,3	0,27
1600	1,0	1,4	0,43
2000	0,8	1,3	0,46
2500	1,0	1,3	0,28
3150	1,0	1,2	0,23
4000	0,9	1,2	0,34
5000	1,0	1,4	0,32

Table VI. Expanded uncertainty associated to R´ (ISO 140-4) calculated by means of the probability propagation method (first column) uncertainties propagation method (second column) and differences (third column) between both methods.

Frequency	U Monte Carlo	U GUM	Difference
100	3,8	3,8	0,05
125	1,6	1,7	0,09
165	2,3	2,3	0,06
200	1,7	1,7	0,04
250	2,3	2,4	0,15
315	3,6	3,7	0,11
400	2,4	2,6	0,13
500	1,6	1,7	0,13
630	2,5	2,6	0,04
800	1,7	1,8	0,12
1000	1,0	1,2	0,17
1250	2,5	2,6	0,08
1600	1,5	1,5	0,08
2000	1,2	1,3	0,12
2500	2,3	2,4	0,11
3150	2,9	2,9	0,00
4000	2,8	3,0	0,16
5000	3,6	3,7	0,08

Table VI. Expanded uncertainty associated to L´nT (ISO 140-7) calculated by means of the probability propagation method (first column) uncertainties propagation method (second column) and differences (third column) between both methods.

3.6 Calculus of the uncertainty associated to the single-number magnitudes

As we have already mentioned, one of the most remarkable advantages of the distributions propagation method is that allows us an easy calculus of the uncertainty associated to single-number magnitudes. In fact, the criteria established in the Spanish Regulation are mainly based on the values of such magnitudes. So, the calculus of the uncertainties associated to ($D_{nT,w}$ + C), ($D_{2m,nTw}$ + Ctr) and L'_{nTw} is of crucial importance to assure the compliance with the specification limit. The uncertainties propagation method based on the GUM does not provide any analytical method for the calculus of this uncertainty. However, the data necessary for the calculus of the uncertainty of the single-number magnitudes is generated during the Monte Carlo simulation process of the uncertainties associated to D_{nT},, $D_{2m,nT}$ and L'_{nT}. During the simulation for each frequency band we generated 1000 values of D_{nT},, $D_{2m,nT}$ and L'_{nT} magnitudes according to expressions (1), (3) and (4) respectively (so we have 1000 groups each one containing 18 values). One value of the single-number magnitude can be calculated comparing each group of 18 values (as a function of the frequency) of the evaluated parameter to the reference curve according to standards ISO 717-1 and ISO 717-2. At the end of the process, we have 1000 values of the single-number magnitude. Supposing the distribution as normal, the mean value is a good estimation of the single-number magnitude and the combined uncertainty can be considered as the standard deviation of the distribution. In our calculus for the different single-number magnitudes the combined uncertainty is ranging between 0,3 and 0,5 dB. Following a similar process the uncertainty associated to C and C_{tr} can be evaluated, ranging the uncertainty values between 0,3 and 0,5 dB. From these values it is easy to evaluated the combined uncertainties associated to ($D_{nT,w}$ + C) and ($D_{2m,nTw}$ + C_{tr}) and so, the expanded uncertainty multiplying by the factor $k = 2$. The final expanded uncertainty is close to 1 dB in the case of L'_{nTw} and it is ranging between 1 and 2 dB for ($D_{nT,w}$ + C), ($D_{2m,nTw}$ + C_{tr}). These values are indicative of a reasonable evaluation of the uncertainty.

4 Conclusions

In summary, due to the exigencies of the different Regulations in Building Acoustics not only the values of the acoustic magnitudes but the uncertainty associated to them have to be calculated in the field measurements. A comparative study of the uncertainty associated to parameters evaluated in field measurements according to ISO 140-4, 140-5 and 140-7 calculated by means of uncertainties propagation method and probabilities propagation method by Monte Carlo simulation have been presented. The software used for the Monte Carlo simulation has been Excel. In parameters associated to field measurements according to ISO 140-4 and 140-5 higher uncertainty values have been obtained by means of the uncertainties propagation method. We believe that this is due to the fact that in the type of expressions of parameters as D_{nT} or R´ the uncertainties are overestimated if we use the uncertainties propagation method. In any case, these differences are no bigger than 0,5 dB, indicating the adequacy of both methods for the uncertainty calculus. However, the main advantage of the probabilities propagation method is that it allows an easy way for the calculus of the uncertainty associated to the single-number magnitudes and the commands for the Monte Carlo simulation are implemented on software programs of easy use as Excel. For all these reasons, we recommend to use Monte Carlo simulation using Excel software in the laboratories preparing their accreditation.

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