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CALIBRATION TECHNIQUE AND UNCERTAINTY EVALUATION OF ACOUSTIC CALIBRATORS

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ABSTRACT

Acoustic calibrator is an acoustic device that emits an audible tone of very accurate level and frequency like 94 dB, 104 dB or 114 dB at 1000 Hz or at many frequencies where it is named in this case by multifunctional acoustic calibrator. It is used for adjusting the sound level meter or analyzer which is one of the most important devices used in the field of acoustic measurements. Checking a meter's calibration is always good practice and essential for many applications. Most regulations, like the noise at work regulations, demand that the meter is calibrated before making measurements. The international documentations are interested in calibration of the acoustic calibrator. One of these documentations is the International Electrotechnical Commission Standards, which indicated the calibration procedures, method and the tolerance limits of the calibrator classes. IEC 60942 is the concerned standard for the acoustic calibrator. The calibration method is more recent one; it is also B&K calibration system type 3630, which is software automation with pulse generator depending on the direct measurement for the level, frequency and harmonic distortion of the acoustic calibrator. This paper presents an overview of calibration of a multifunction acoustic calibrator and evaluation of uncertainty in details.

Keywords: *Acoustic calibrator, pulse generator, harmonic distortion*

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1. INTRODUCTION

Most acoustical calibration laboratories, as well as national measurement institutes, undertake calibrations of acoustic calibrators because of the widespread use of the sound calibrator in making traceable acoustical measurements. Acoustic calibrators including pistonphones, sound level calibrator and multi-frequency calibrator, are sound sources designed to produce a known sound pressure level at a certain frequency. The International Standard IEC 60942:2003[1] specifies the calibration procedures and method for the acoustic calibrator also the tolerance limits of the calibrator classes. V Plangsangmas et al.{Plangsangmas, 2014 } summarized the results of a regional supplementary comparison APMP.AUV.A-S1[2] that carried out for calibration of multifunctional sound calibrator, 13 NMIs participated in the comparison and the report include the obtained measurement recorded by the participants and their uncertainties. It has been found that a term for the inherent instability in this type of device needs to be included in uncertainty budget.
This research aim at presenting and reporting the results of the calibration method for acoustic calibrator (B&K 4231,4226) at the reference sound pressure levels(SPLs) 94dB and 114dB for the different frequencies (31.5, 63, 125 , 250 , 500 , 1000 , 2000 , 4000 , 8000 , 12500 and 16000) Hz. The proposed method discussed in details with analyzing the measurement uncertainty based on the international documents "GUM" [3].

2. EXPERIMENTAL WORK

Calibration of acoustic calibrators can be carried out using B&K pulse multi analyzer automated system type 3630. The software of the system can perform the calibration at any single tone of different frequencies. The main work of this system is depending on comparison the direct measurement of the output date from the device under calibration. Fig. 1 shows the B&K pulse multi analyzer automated system type 3630. The calibrator under test was calibrated for levels 94 dB and 114 dB at 1000 Hz. the calibration has been performed according to the procedures and precautions of IEC 60942. The emitted sound level from the calibrator was measured by LS2 microphone B&K type 4180, which connected to Module type 3110, the signal is proceed via the software of the system where the sound pressure level (SPL_{cal}), frequency (f) and harmonic distortion (THD) are showed directly on the monitor. Before the calibration, ambient pressure, temperature and humidity have been recorded, some precautions are taken to insure that there is no any physical damage for calibrator and measuring microphone, and they must be free from foreign particles.

Figure 1. B&K pulse multi analyzer automated system type 3630

Table 1. Measured Level SPL (dB)

Used method	94 dB				114 dB			
	SPL (dB)	Accepted tolerance limits (dB)		Expanded Uncertainty (dB) at 95%	SPL (dB)	Accepted tolerance limits (dB)		Expanded Uncertainty (dB) at 95%
		Lower limit	Upper limit			Lower limit	Upper limit	
New	94.01	93.75	94.25	0.19	114.00	114.25	113.75	0.17

Table 2. Measured Frequency f (Hz)

Used method	At 94 dB				At 114 dB			
	f (Hz)	Accepted tolerance limits (Hz)		Expanded Uncertainty (Hz) at 95%	f (Hz)	Accepted tolerance limits (Hz)		Expanded Uncertainty (Hz) at 95%
		Lower limit	Upper limit			Lower limit	Upper limit	
New	1005.09	1004.00	1006.00	0.10	1005.10	1004.00	1006.00	0.10

3. CALIBRATION OF ACOUSTIC CALIBRATOR TYPE B&K 4231

The acoustic calibrator type B&K 4231 has been calibrated at levels 94 dB & 114 dB of frequency 1000 Hz. The obtained results of SPL, frequency and THD are tabulated in table 1, 2 and 3.

Table 3. Measured Harmonic Distortions THD (%)

Used method	94 dB			114 dB		
	THD %	Accepted tolerance limits (%)	Expanded Uncertainty (%) at 95%	THD %	Accepted tolerance limits (%)	Expanded Uncertainty (%) at 95%
New	0.07	2	0.055	0.21	2	0.100

4. RESULTS AND DISCUSSIONS

4.1 Sound pressure level

In order to carry out the calibration of multifunction acoustic calibrator at different frequencies, so trial to calibrate acoustic calibrator type B&K 4231 at 1000Hz.

The values of SPL (94 & 114) dB at different frequencies (31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, 12500 and 16000) Hz obtained from calibration of multifunction acoustical calibrator type B&K 4226 (LS) using this method.

Also, the corrections of SPL for the standard microphone used in the measurements were taken into consideration. One can make the corrections from the calibration certificate, where at each frequency one can add or subtract the deviation from the measurements. It is clear from the figure that the measured values using in this method. Where the differences were in order of magnitude 0.01dB through all the tested frequencies at the ambient condition. Also, the calculated values at the reference conditions for this method was nearly the same (deviation in order of magnitude of 0.001dB). The obtained measured value of SPL by using the this method was within the accepted limits for LS Multifunction acoustic calibrator as stated in the standard.

Table 4. Pressure and temperature coefficients for the calibrator at 1/3 octave band frequencies.

Frequency (Hz)	**Pressure coefficient (dB/kPa)**	**Temperature coefficient(dB/K)**
31.5	0.0052	0.0011
63	0.0052	0.0011
125	0.0053	0.0011
250	0.0054	0.0011
500	0.0056	0.0011
1000	0.0056	0.0012
2000	0.0051	0.0017
4000	0.0035	0.0028
8000	-0.0015	0.0069
12.500	-0.0077	0.0142
16.000	-0.0018	0.015

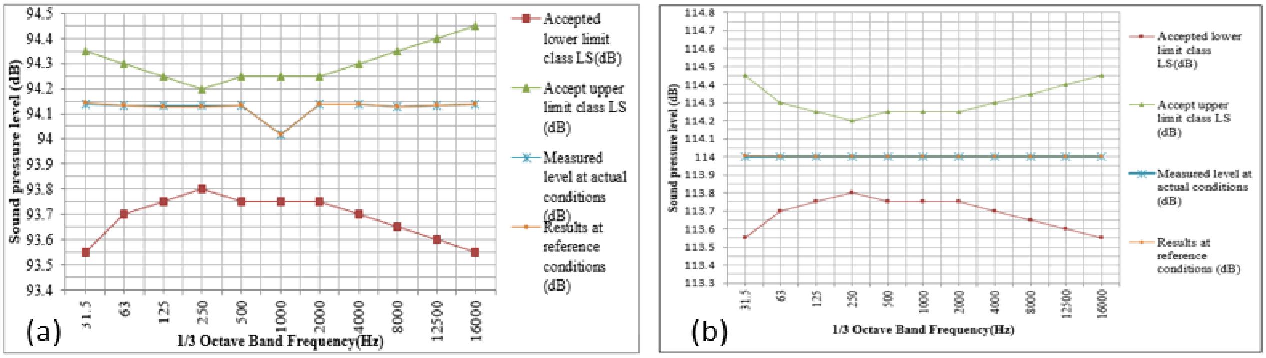

Figure 2. The measured SPL (dB) obtained versus 1/3 octave band frequency for the method used (a) - at level 94dB (b)-at level 114dB

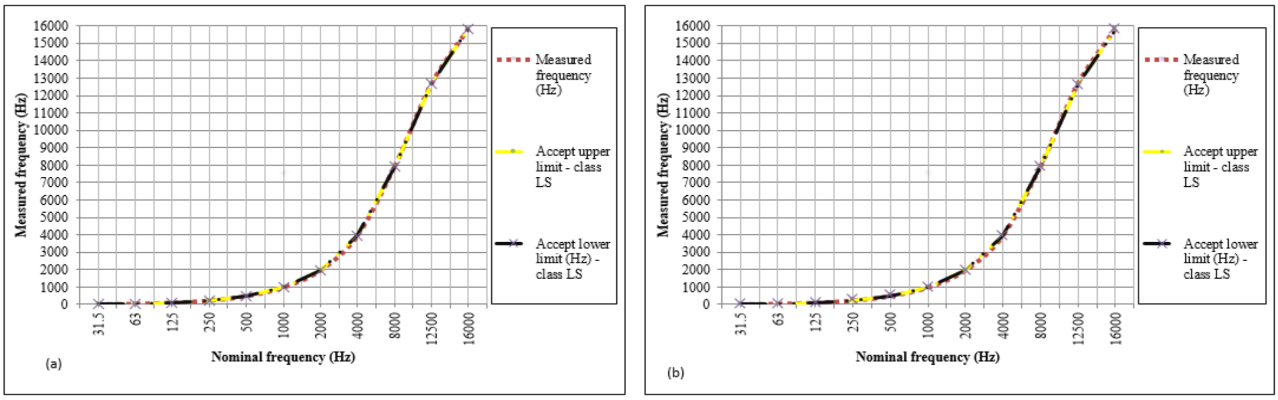

Figure 3. The measured Frequency (Hz) obtained versus 1/3 octave band frequency for the new method used (A)- at level 94dB (B)-at level 114dB.

4.2 Frequency

The frequency of the sound generated by the sound calibrator coupled to the microphone used in B.3.4(in the Annex of IEC) shall be measured, at the principal sound pressure level, for each frequency setting of the sound calibrator for which the instruction manual states that the instrument conforms to the requirements of this standard.

4.3. Total Harmonic Distortion (THD)

The frequency of the sound generated by the sound calibrator coupled to the microphone used in B.3.4 shall be measured, at the principal sound pressure level, for each frequency setting of requirements of this standard.

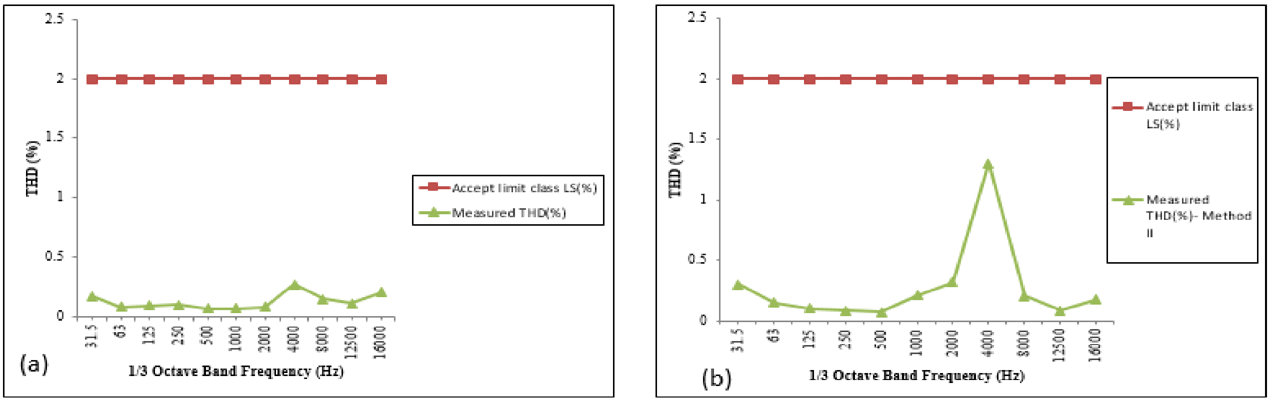

Figure 4. The measured THD (%) obtained versus 1/3 octave band frequency for this method used (A)- at level 94dB (B)-at level 114dB.

5. UNCERTAINTY ANALYSIS

5.1 Uncertainty Components

A- Reference microphone

Calibration of reference microphone used (Type A, Normal distribution)

The microphone coupled to calibrator is of IEC type LS2, the reported uncertainties lies in the range of 0.015-0.025dB within the frequency range of 20-20000 Hz. The used microphone is a standard reference microphone of type B&K 4180. It was calibrated using primary calibration system (reciprocity method) according to the standard IEC 61094-2:2009. It means that uncertainty value obtained from the calibration certificate[4].

Drift in sensitivity level between two successive calibrations (Type B, Normal distribution)

The sensitivity levels of the microphones have be seen to drift by a small amount between calibrations, Uncertainties for an interval between calibrations of the reference standard of two times, it lies in the range of 0.0087 – 0.10dB within the audible frequency range.

Difference in sensitivity level between calibration frequencies (Type B, Rectangular distribution)

The sensitivity level of the reference microphone may differ between the frequency at which it is calibrated and the frequency of the calibrator under test. The difference in uncertainty of pressure sensitivity between the frequencies of interest, it lies in the range 0.00080 – 0.115dB within the frequency range.

Influence of environmental conditions (static pressure, air temperature, relative humidity) (Type B, Rectangular distribution)

The influence of any deviation from reference environmental conditions on the sound pressure level is well established for most models. It lies in the order of magnitude of (a- pressure {0.0016}) , (b-temperature { 4.61013E-06 - 0.0030}) and (c-humidity-{0.00062 – 0.00065}) for any error in the applied correction, and estimation of uncertainty .

Components contributed to the uncertainty of temperature. The first component is uncertainty of temperature indicated by a reference thermometer (data logger test 175H1. The calibration certificate of the reference thermometer showed that this uncertainty (type B, rectangular). Also, the third component is fluctuation of temperature during the measurement.

The sensitivity coefficient for temperature:

$$\frac{6.5}{273+\theta}+\frac{-0.57+0.25\log(2.6freq.)}{1+0.0011H+0.007\theta} \quad (1)$$

H: humidity, θ: temperature

The sensitivity coefficient for humidity:

$$\frac{-2.6+1.6\log(0.7freq.)}{1+0.5H} \quad (2)$$

Components contributed to the uncertainty of static pressure. The first component is uncertainty of static pressure indicated by a barometer from the calibration certificate of the barometer showed that this uncertainty (type B, rectangular). The other component is fluctuation of static pressure during the measurement.

Two components contributed to the uncertainty of humidity. The first component is uncertainty of humidity indicated by a hygrometer from the calibration certificate of the hygrometer showed that this uncertainty (type B, rectangular). The second component is fluctuation of humidity during the measurement.

Conversion of % to dB

$$u(dB) = 20\log\left(1+\frac{u(\%)}{100}\right) \tag{3}$$

$$u(\%) = 100.(10^{\frac{u(dB)}{20}} - 1) \tag{4}$$

Polarizing voltage (Type B, Rectangular distribution)

Where the polarizing voltage applied to the microphone strays from the nominal value, an error in the sensitivity level of the microphone is introduced. The uncertainty is 0.00017dB.

B- Calibrator under test

The characteristics of calibrator is known:

Effective load volume of microphone (Type B, Rectangular distribution)

The sound pressure level of the calibrator is measured at the diaphragm of a microphone that is coupled to the calibrator. Therefore, the measured sound pressure level is dependent on the geometry of the microphone and the susceptibility of the calibrator to changes in the effective load volume of the microphone. For convenience, the influence of these effects is discussed in this section. The difference in the level of a calibrator coupled to microphones of different effective load volumes is well known.

A correction for the difference between the actual effective load volume of the microphone and the nominal value for the calibrator.

Influence of environmental conditions (static pressure, air temperature, relative humidity) (Type B, Rectangular distribution)

Modern models of electronic sound calibrator generally have very small sensitivities to changes in static pressure, while some models may show widely varying changes in sound pressure level.

Performing the calibration in rooms that provide control temperature to within ± 1 °C of the reference temperature of 23 °C, Relative humidity may also be controlled.

Measurement method (1-Sound pressure level)

Repeatability of SPL (Type A, Normal distribution)

Laboratory perform ten replications of the measurements in order to establish the repeatability of the test, calculate a Type A uncertainty contribution, based on either the actual results of the repeatability.

Resolution of reported SPL (Type B, Rectangular distribution)

Reporting the sound pressure level to two decimal places of decibels and therefore include an uncertainty term of magnitude.

Error in the voltage (Type B, Rectangular distribution)

Uncertainty in calibration of the voltmeter from the calibration certificate.

Conversion of V to dB or reverse

$$dB=20\log V \quad , V=10^{dB/20} \tag{5}$$

Frequency

Repeatability of frequency (Type A, Normal distribution)

Laboratory perform ten replications of the measurements in order to establish the repeatability of the test, calculate a Type A uncertainty contribution, based on either the actual results of the repeatability.

Calibration of DMM (calibration certificate) (Type A, Normal distribution)

The DMM used is previously calibrated with its certificate and uncertainty value. The uncertainty in the calibration certificate was in ppm and to convert it in to Hz, we can use the conversion,

U(Hz) = U(ppm)*freq./1000000 (6)

Rounding error (Type B, Rectangular distribution)

The result is reported interim results rounded off to the 0.01Hz, giving a semi -range of 0.002 Hz with a rectangular distribution.

Accuracy of the meter to measure frequency (Type B, Rectangular distribution)

Adding or subtracting the error value in the calibration certificate of generator at each frequency.

Total harmonic distortion THD

Repeatability of THD (Type A, Normal distribution)

Laboratory perform ten replications of the measurements in order to establish the repeatability of the test, calculate a Type A uncertainty contribution, based on either the actual results of the repeatability.

Resolution (Type B, Rectangular distribution)

How small of change can be read 0.01% with the used device

Accuracy of pulse (Type A, Normal distribution)

The pulse generator used is previously calibrated with its certificate and uncertainty values.

Rounding error (Type B, Rectangular distribution)

The result is reported with a resolution of 0.01 %, giving a semi -range of 0.002 % with a rectangular distribution

Instability for distortion readings (Type B, Rectangular distribution)

Fluctuation that may be occurred in the reading values during the measurements

Microphone Distortion (Type B, Rectangular distribution)

The standard microphone B&K 4180 used has distortion value that can affect the THD% value during the calibration. So, it must be taken in consideration.

Pre-amplifier Distortion (Type B, Rectangular distribution)

The pre-amplifier has a distortion value that must be taken in consideration.

The components of uncertainty for each aspect of the measurements performed. The discussion is mostly based on the reported uncertainty budgets for pistonphone coupled to IEC type LS2P microphone.

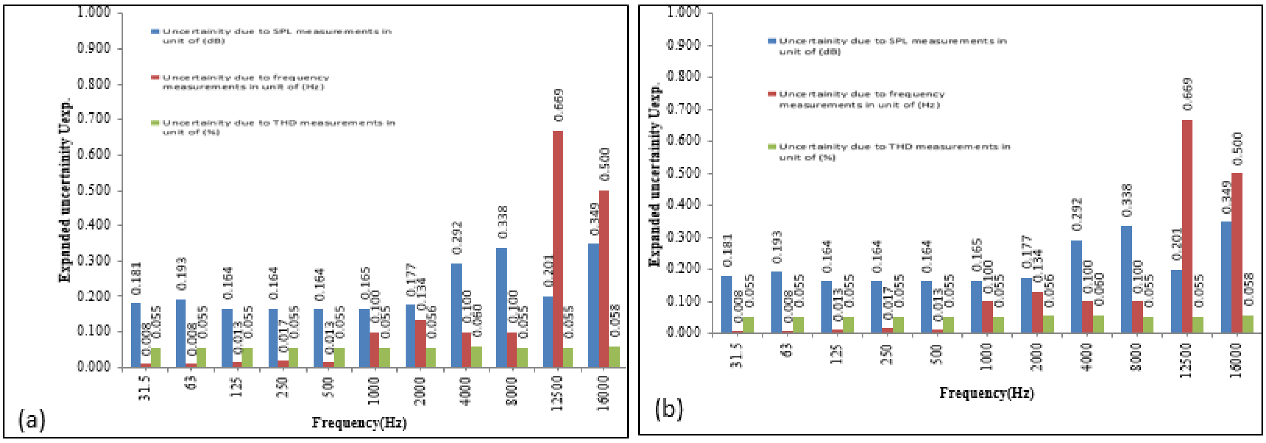

Figure 5. Expanded Uncertainty for all the measurements SPL, freq. and THD by this method (I&II) (A)-level 94dB, (B) level 114dB.

The U_{exp}. for the frequency measurements lies in the range of 0.08-0.66 Hz for these method within the frequency range. Also, the U_{exp}. for the THD measurements lies in the range of 0.05-0.09% for these method, within the frequency range. It is clear from the figure **5** that for the SPL measurements the U_{exp}.lies in the range 0.18-0.34dB for the method, within the 1/3 octave band frequency from 31.5-16000Hz. The U_{exp}. for the frequency measurements lies in the range of 0.008-0.66Hz for this method, within the frequency range. Also, the U_{exp}. for the THD measurements lies in the range of 0.05-0.058% for this method, within the frequency range.

5. CONCLUSIONS

In the calibration method, it was recommended to use high level standard microphone, and not preferable to use working microphone. The results of SPL(dB), frequency(Hz) and THD(%) measured for multifunction acoustic calibrator were obtained at both levels 94&114dB and at different 1/3 octave frequencies. From the measurements, the obtained values lie within acceptable limits. It may be clear that the uncertainty values for this method was small. The uncertainty calculation was very complicated and need expert to estimate. It was clear from the discussion that the values of expanded uncertainty for SPL, frequency and THD were small and may be used for NMI as NMCC.

REFERENCES

[1] I.E. Commission, IEC 60942: 2003, Electroacoustics—Sound Calibrators (2003).

[2] Plangsangmas, V., Leeudomwong, S., Scott, A., Zhong, B., & Huang, Y. (2014). Final report on the regional supplementary comparison APMP. AUV. A-S1. Metrologia, 51(1A), 09004-09004.

[3] Iso, I., & OIML, B. (1995). Guide to the Expression of Uncertainty in Measurement. *Geneva, Switzerland*, *122*, 16-17..

[4] G. DE ARCAS, M. RUIZ, J.M. LOPEZ, M. RECUERO, R. FRAILE, A Virtual Instrument to Evaluate the Uncertainty of Measurement in the Calibration of Sound Calibrators, Advanced Mathematical And Computational Tools In Metrology VII, World Scientific2006, pp. 119-129.