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Calibration Methodologies and the Accuracy of Acoustic Data

Craig BEYERS[1]

[1] Air Noise Environment Pty Ltd, Australia

ABSTRACT

The precision and accuracy of acoustic instrument calibrations is fundamental in ensuring the validity and defensibility of acoustic measurements. The measurement error is additive to the overall uncertainty or error associated with acoustic calculations and modelling techniques, where these rely on measurement data as a source of acoustic data. Therefore, the tolerance of the calibration is a fundamental component in determining the accuracy of all applications that rely on acoustic measurement data.

National and International metrology standards define the methodologies adopted in acoustic calibration. Currently the IEC 61672 standard is adopted for the periodic testing of field instruments.

This paper provides an overview of the changes in calibration requirements of the IEC 61672 standard relative to the earlier versions of IEC 61672 and the IEC 652 standard. The paper then explores in more detail from an end user perspective the implications of calibration methodologies and the overall accuracy of acoustic data.

Keywords: Sound, Calibration, Measurement Uncertainty

1. INTRODUCTION

Sound level meters (SLMs) provide an important tool informing design and decision making processes in a wide range of fields. Ensuring the results provided by these instruments are reliable and within a known and quantified level of uncertainty is of critical importance to these activities.

Recent changes to the International Standards which govern the verification of the performance of SLMs have resulted in changes to not only the testing procedures adopted during the performance verification process but also to the methods of assessing compliance with the acceptable tolerances. To gain a better understanding of the potential influence of these changes on the end user of the SLM, this paper provides an analysis of the differences between the current and previous version of standards. In doing so, the analysis identifies that, for most Australian calibration laboratories, the changes to the standards could result in a tightening of the compliance limits for the performance verification of SLMs.

2. IMPORTANCE OF CALIBRATION

Noise exposure has potential implications for health and wellbeing in the community including specific effects such as: noise-induced hearing impairment; interference with speech communication; disturbance of rest and sleep; psychophysiological, mental-health and performance effects; effects on residential behaviour and annoyance; as well as interference with intended activities. Understanding the potential for these impacts to occur is a significant component of a range of activities including investigating complaints, assessing the number of persons exposed to a particular noise source, determine compliance with regulations, land use planning and environmental impact assessments, evaluation of remedial measures, calibration and validation of predictions, research surveys and trend monitoring. Without access to accurate traceable measurement data, determining potential outcomes and assessing compliance for any of these

[1] Craig.Beyers@ane.com.au

activities could reasonably be called into question. This could for example, result in regulators being unable to enforce noise regulations on a particular activity with any certainty.

Establishing the traceability of noise measurements starts with the design and construction of the sound level meter and microphone and continues throughout the life of the instrument with periodic verification of performance and routine checking of instrument sensitivity using a calibrated acoustic calibrator or piston phone. Failure to undertake any one of these steps could result in measurement data that is untraceable, inaccurate and unreliable for its intended purpose.

This fact is even more apparent in modern society as a result of the influx of low cost sound level meters and mobile phone applications claiming to be able to provide noise measurements. While many of these instruments may in fact be capable of providing a reliable response to a 94dB at 1kHz signal from an acoustic calibrator, their ability to provide reliable measurement of the simplest sound pressure level in dB(A) of broadband noise requires more detailed testing and assessment of performance.

3. PERFORMANCE VERIFICATION

Periodic testing of sound level meters is undertaken on a biannual basis in Australia based on regulatory requirements provided by a number of agencies in Australia (1). In Australia, the periodic testing of sound level meters is undertaken in accordance with Australian and International standards including AS 1259.2 (2) and IEC 61672-3 (3) depending on the type of instrument being calibrated. In selecting the type of calibration required the laboratory and end user of the equipment needs to consider the specifications of the instrument (including the manufacturers claim of conformance to a particular standard), the requirements for the later use of the instrument and specific client requirements including the history of calibration of the instrument.

In requesting and reviewing performance calibration information it is necessary for the end user to understand the results provided, be able to identify differences from previous performance verification reports and understand the uncertainty of measurement associated with each of the measurements undertaken. Without this, the end user may in fact be using a sound level meter for purposes for which it may be unreliable thereby increasing the uncertainty of any measurement results.

In Australia, performance verification is undertaken by laboratories with quality assurance systems and calibration procedures independently accredited by the National Association for Testing Authorities (NATA). A key component of this accreditation process involves estimation of the uncertainty for each of the calibrations undertaken. This uncertainty information, while often overlooked by the end user, is a key component of the calibration and determines the ability of the instrument to perform in accordance with the requirements of the standard.

In Australia, for the end user, conformance of calibration laboratories with the requirements of these specifications for periodic performance testing is demonstrated through independent accreditation by the National Association of Testing Authorities (NATA). While for many, a calibration certificate for a SLM provided by a NATA accredited laboratory may represent all the information they require to confirm compliance, the uncertainty associated with the performance verification testing procedures can in fact result in changes to the uncertainty of both measurements and decisions being made.

4. HISTORY OF PERFORMANCE STANDARDS

The history and development of performance specifications and periodic verification has been discussed in detail by a number of authors in the past including Narang and Bell (4), Meldrum (5) and Tyler (6). The development and implementation of the IEC 61672 parts 1-3 (7, 8) Standards represent a response to advances in technology which resulted in many components of the previous standards being largely irrelevant (4).

In 2002 IEC 61672 was published as a replacement for the previous (2)IEC 60651 Standard and IEC 60804 Standard. These older standards which form the basis of the Australian Standards AS1259.1 (9) and AS 1259.2 (2) provided specifications for the design and manufacture of sound level meters. At the time of their publication, these standards were to a large extent obsolete as a result of the rapid technological advances which resulted in the widespread adoption of digital displays and digital signal processing (5).

IEC 61672: Part 1 provided a response to these advances and incorporated specifications considered necessary to ensure consistency across the measurement capabilities provided in these new generation meters. To achieve this, instruments were classified in accordance with two performance standards, Class 1 and Class 2. Class 1 SLMs were intended to provide precision grade instruments with a higher accuracy for laboratory and field use. Class 2 instruments were classified to provide instruments suitable for general field use with a lower performance specification. The specific performance objectives of both instrument classes provided in IEC 61672 are essentially identical with variation provided between the allowable tolerances for each class of instrument.

Importantly, the IEC 61672-3:2006 Standard provides testing requirements for the verification of SLM performance. These requirements, previously not incorporated into international standards, provided a means of standardizing the testing of instruments undertaken. The procedures defined in IEC 61672-3 were intended to "… assure the user that the performance of a sound level meter conforms to the requirements of IEC 61672-1:2002 for a limited set of key tests …"(8). This important addition sought to ensure that the periodic testing of sound level meters was performance in a consistent manner by all laboratories.

In 2013, IEC 61672-3 was revised incorporating a number of changes to both the tests applied during performance verification of sound level meters and to the way in which performance is assessed against the specifications.

5. IEC 61672-3: 2013

Changes in the Treatment of Uncertainty

In 2013, a new version of IEC61672.3 was published. This standard, which controls the performance verification of modern sound level meters, included a number of important changes to both the testing undertaken and the way the results of testing (and therefore compliance) are interpreted.

The superseded version of IEC 61672.3 provided a methodology whereby the performance of the instrument for a given test, when extended by the uncertainty of measurement, was compared with acceptable performance limits as defined in IEC 61672.1. In doing so, where a laboratory undertaking the performance verification of an instrument had a relatively high measurement uncertainty, the allowable variation for a given instrument was reduced in real terms. Conversely, a laboratory with a lower measurement uncertainty is able to provide performance verification for an instrument where measured deviations from the standard are significantly closer to the acceptable tolerances.

The current 2013 revision to the standard amended this approach such that two independent criteria are applied to the performance verification process. The first criterion is applied to the testing laboratory itself through the specification of a maximum uncertainty of measurement for each test. Providing the testing methodology complies with this maximum uncertainty of measurement, the performance testing procedures are considered valid. The second criterion compares directly the measurement result for an individual performance test against the performance specification provided in IEC 61672-1. In doing so, the new methodology allows for similar results to be reported by laboratories with differing uncertainties of measurement (providing the laboratory uncertainty complies with minimum requirements of the standard). To accommodate this change, variations to the specifications included in IEC 61672-1 were necessary. Tables 1, 2 and 3 below provide a summary of the variations to the performance specifications for instruments as provided in IEC 61672-1.

Table 1: Comparison of Performance Specifications

Requirement	Permissable Tolerance				Maximum expanded uncertainty	
	IEC 61671-1: 2004		IEC 61671-1: 2013			
	Class 1	Class 2	Class 1	Class 2	IEC 61671-1: 2004	IEC 61671-1: 2013
Frequency weightings A, C, Z, FLAT *10Hz to 200 Hz*	Table 2 below	Table 2 below	Table 2 below	Table 2 below	0.5	0.6
>200Hz to 1.25kHz	Table 2 below	Table 2 below	Table 2 below	Table 2 below	0.4	0.6
>1.25kHz to 4kHz	Table 2 below	Table 2 below	Table 2 below	Table 2 below	0.6	0.6
>4kHz to 10kHz	Table 2 below	Table 2 below	Table 2 below	Table 2 below	0.6	0.7
>10kHz to 20kHz	Table 2 below	Table 2 below	Table 2 below	Table 2 below	1	1
A vs C, Z, or FLAT at 1 kHz	0.4	0.4	0.2	0.2	0.2	0.2
Level linearity error	1.1	1.4	0.3	0.5	0.3	0.3
1 dB to 10 dB change in level	1.1	1.4	0.3	0.5	0.3	0.25
F vs S level at 1 kHz	0.3	0.3	0.1	0.1	0.2	0.2
Toneburst response	Table 3 below	Table 3 below	Table 3 below	Table 3 below	0.3	0.3
Repeated tonebursts	Table 3 below	Table 3 below	Table 3 below	Table 3 below	0.3	0.3
Overload indication	1.8	1.8	1.5	1.5	0.3	0.25
Peak C sound levels	1.4	2.4	1	2	0.4	0.35
Stability during continuous operation	-	-	0.1	0.3	-	0.1
High-level stability	-	-	0.1	0.3	-	0.1

Table 2: Comparison of Frequency Weightings and Tolerance Limits

Nominal	Frequency weightings (dB)			IEC 61672-1: 2003				IEC 61672-1: 2003		
				Tolerance limits (dB)		Uncertainty		Tolerance limits (dB)		Uncertainty
				Class		Class		Class		Class
Hz	A	C	Z	1	2	1	2	1	2	1 & 2
10	–70,4	–14,3	0,0	+3,5; –	+5,5; –	-0.5	-0.5	+3,0; -∞	+5,0; -∞	0.6
12,5	–63,4	–11,2	0,0	+3,0; –	+5,5; –	-0.5	-0.5	+2,5; -∞	+5,0; -∞	0.6
16	–56,7	–8,5	0,0	+2,5; –4,5	+5,5; –	-0.5	-0.5	+2,0; -4,0	+5,0; -∞	0.6
20	–50,5	–6,2	0,0	2,5	3,5	-0.5	-0.5	±2,0	±3,0	0.6
25	–44,7	–4,4	0,0	+2,5; -2,0	3,5	-0.5	-0.5	+2,0; -1,5	±3,0	0.6
31,5	–39,4	–3,0	0,0	2,0	3,5	-0.5	-0.5	±1,5	±3,0	0.6
40	–34,6	–2,0	0,0	1,5	2,5	-0.5	-0.5	±1,0	±2,0	0.6
50	–30,2	–1,3	0,0	1,5	2,5	-0.5	-0.5	±1,0	±2,0	0.6
63	–26,2	–0,8	0,0	1,5	2,5	-0.5	-0.5	±1,0	±2,0	0.6
80	–22,5	–0,5	0,0	1,5	2,5	-0.5	-0.5	±1,0	±2,0	0.6
100	–19,1	–0,3	0,0	1,5	2,0	-0.5	-0.5	±1,0	±1,5	0.6
125	–16,1	–0,2	0,0	1,5	2,0	-0.5	-0.5	±1,0	±1,5	0.6
160	–13,4	–0,1	0,0	1,5	2,0	-0.5	-0.5	±1,0	±1,5	0.6
200	–10,9	0,0	0,0	1,5	2,0	-0.5	-0.5	±1,0	±1,5	0.6
250	–8,6	0,0	0,0	1,4	1,9	-0.4	-0.4	±1,0	±1,5	0.6
315	–6,6	0,0	0,0	1,4	1,9	-0.4	-0.4	±1,0	±1,5	0.6
400	–4,8	0,0	0,0	1,4	1,9	-0.4	-0.4	±1,0	±1,5	0.6
500	–3,2	0,0	0,0	1,4	1,9	-0.4	-0.4	±1,0	±1,5	0.6
630	–1,9	0,0	0,0	1,4	1,9	-0.4	-0.4	±1,0	±1,5	0.6
800	–0,8	0,0	0,0	1,4	1,9	-0.4	-0.4	±1,0	±1,5	0.6
1 000	0	0	0	1,1	1,4	-0.4	-0.4	±0,7	±1,0	0.6
1 250	+0,6	0,0	0,0	1,4	1,9	-0.4	-0.4	±1,0	±1,5	0.6
1 600	+1,0	–0,1	0,0	1,6	2,6	-0.6	-0.6	±1,0	±2,0	0.6
2 000	+1,2	–0,2	0,0	1,6	2,6	-0.6	-0.6	±1,0	±2,0	0.6
2 500	+1,3	–0,3	0,0	1,6	3,1	-0.6	-0.6	±1,0	±2,5	0.6
3 150	+1,2	–0,5	0,0	1,6	3,1	-0.6	-0.6	±1,0	±2,5	0.6
4 000	+1,0	–0,8	0,0	1,6	3,6	-0.6	-0.6	±1,0	±3,0	0.6
5 000	+0,5	–1,3	0,0	2,1	4,1	-0.6	-0.6	±1,5	±3,5	0.7
6 300	–0,1	–2,0	0,0	+2,1; -2,6	5,1	-0.6	-0.6	+1,5; -2.0	±4,5	0.7
8 000	–1,1	–3,0	0,0	+2,1; -3,1	5,6	-0.6	-0.6	+1,5; -2,5	±5,0	0.7
10 000	–2,5	–4,4	0,0	+2,6; -3,6	+5,6; -	-0.6	-0.6	+2,0; -3,0	+5,0; -∞	0.7
12 500	–4,3	–6,2	0,0	+3,0; -6,0	+6,0; -	-1	-1	+2,0; -5,0	+5,0; -∞	1
16 000	–6,6	–8,5	0,0	+3,5; -17,0	+6,0; -	-1	-1	+2,5; -16,0	+5,0; -∞	1
20 000	–9,3	–11,2	0,0	+4,0; -	+6,0; -	-1	-1	+3,0; -∞	+5,0; -∞	1

Table 3: Comparison of Reference 4kHz Toneburst Response and Acceptance Limits

Toneburst duration, T_b ms	Reference 4 kHz toneburst response, δref, relative to the steady sound level dB		IEC 61672-1: 2003 Performance class		IEC 61672-1: 2013 Performance class	
	$L_{AFmax} - L_A$ $L_{CFmax} - L_C$ and $L_{ZFmax} - L_Z$; Eq. (7)	$L_{AE} - L_A$ $L_{CE} - L_C$ and $L_{ZE} - L_Z$; Eq. (8)	1	2	1	2
1 000	0,0	0,0	0,8	1,3	±0,5	±1,0
500	-0,1	-3,0	0,8	1,3	±0,5	±1,0
200	-1,0	-7,0	0,8	1,3	±0,5	±1,0
100	-2,6	-10,0	1,3	1,3	±1,0	±1,0
50	-4,8	-13,0	1,3	+1,3; –1,8	±1,0	+1,0; -1,5
20	-8,3	-17,0	1,3	+1,3; –2,3	±1,0	+1,0; -2,0
10	-11,1	-20,0	1,3	+1,3; –2,3	±1,0	+1,0; -2,0
5	-14,1	-23,0	1,3	+1,3; –2,8	±1,0	+1,0; -2,5
2	-18,0	-27,0	+1,3; –1,8	+1,3; –2,8	+1,0; -1,5	+1,0; -2,5
1	-21,0	-30,0	+1,3; –2,3	+1,3; –3,3	+1,0; -2,0	+1,0; -3,0
0,5	-24,0	-33,0	+1,3; –2,8	+1,3; –4,3	+1,0; -2,5	+1,0; -4,0
0,25	-27,0	-36,0	+1,3; –3,3	+1,8; –5,3	+1,0; -3,0	+1,5; -5,0
	$L_{ASmax} - L_A$ $L_{CSmax} - L_C$ and $L_{ZSmax} - L_Z$; Eq. (7)					
1 000	-2,0		0,8	1,3	±0,5	±1,0
500	-4,1		0,8	1,3	±0,5	±1,0
200	-7,4		0,8	1,3	±0,5	±1,0
100	-10,2				±1,0	±1,0
50	-13,1				±1,0	+1,0; -1,5
20	-17,0				+1,0; -1,5	+1,0; -2,0
10	-20,0				+1,0; -2,0	+1,0; -3,0
5	-23,0				+1,0; -2,5	+1,0; -4,0
2	-27,0				+1,0; -3,0	+1,0; -5,0

NOTE 1 For the purpose of this standard and for time-weighting sound level meters, reference 4-kHz toneburst response δ_{ref} for maximum time-weighted sound levels is determined from the following approximation

$$\delta_{ref} = 10 \lg (1 - e^{-T_b/\tau}) \text{ dB} \quad (7)$$

where

T_b is a specified duration of a toneburst in seconds, for example from column 1, τ is a standard exponential time constant as specified in 5.8.1, and e is the base of the natural logarithm.

Equation (7) applies for isolated 4 kHz tonebursts.

NOTE 2 For the purpose of this standard and for integrating and integrating-averaging sound level meters, reference 4-kHz toneburst response δ_{ref} for sound exposure levels is determined from the following approximation:

$$\delta_{ref} = 10 \lg (T_b / T_0) \text{ dB} \quad (8)$$

where

T_b is a specified duration of a toneburst in seconds, for example from column 1, and T_0 is the reference value of 1 s for sound exposure level.

NOTE 3 Reference 4-kHz toneburst responses in Table 4 are valid for the A, C, and Z frequency weightings.

Other frequency weightings can have other reference toneburst responses.

Additional Testing Procedures

The current version of IEC 61672-3, in addition to changes relating to the treatment of uncertainty, also include two additional performance tests assessing measurement stability for inclusion in routine performance testing of SLMs.

The first of these additional tests include an assessment of the long term stability of the SLM measurement when exposed to a continuous 1 kHz signal at the reference sound pressure level (typically 94 dB or 114 dB) for between 25 and 35 minutes. The second test considers the stability of the SLM when measuring high noise levels. The new testing procedure requires a 1 kHz signal at a level 1 dB less than the instruments upper noise limit to be applied continuously for a period of 5 minutes. Instrument performance is evaluated as the difference in measured A-weighted sound pressure level as recorded at the beginning and end of the 5 minute period.

For both of these stability tests, the allowable variation in measured noise level over the testing period is specified in IEC 61672-1 as within 0.1 dB for Class 1 and 0.3 dB for Class 2 instruments.

It is noted that both of these tests relate to measurement of electronic signals produced by a signal generator. As such they relate to electrical tests only and do not include any additional testing of the instrument microphone.

6. IMPLICATIONS FOR PRACTITIONERS

To understand the key differences between the previous (2004) performance standards and those provided in the 2013 revision of IEC 61672-1, it is necessary to understand the concept of uncertainty as it applies to the measurement requirements provided in the standards. The process of measurement of the performance of a SLM for a given test is an experimental process. In this case, an electrical signal is generated by the calibration system at a specific frequency and level and is applied to the SLM preamplifier input with a response, in dB, produced by the SLM.

The uncertainty of the measurement is the parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the observed result (10). In this case, the uncertainty of the response provided by the SLM will be affected by a range of factors including the uncertainty associated with the signal generated by the system (both level and frequency) and the number of significant figures displayed on the SLM (typically 0.1 dB).

Comparison of the differences between the 2004 and 2013 versions of the IEC 61672-1 and IEC 61672-3 standards shows that, for most laboratories in Australia (with a least uncertainty of measurement for electronic tests of 0.09dB), the current standard offers a tightening of the tolerance limits. For example, for performance verification testing of level linearity of a Class 1 instrument, the allowable variation under the 2004 standard (assuming a laboratory least uncertainty of 0.09dB) was 1.01dB. Under the current standard, the allowable tolerance is reduced to 0.3dB for a Class 1 instrument.

Hence there is potential for some instruments to fail a given test when assessed in accordance with IEC 61672-3:2013 where it would otherwise have passed if tested in accordance with the 2004 version of the standard. In this situation, the SLM in use by an acoustician up to the calibration can be found to be out of calibration and unusable even though the actual instrument performance may not have changed from its state since new.

7. CONCLUSIONS

Sound level meters (SLMs) provide an important tool informing design and decision making processes in a wide range of fields. For laboratories and acousticians in Australia, the introduction of the revised IEC 61672 (Parts 1 and 3) standards provide both new testing requirements and new techniques for assessing compliance with the allowable tolerance of the measurement data provided. Review of the differences between the previous standards and the current revisions has identified a range of differences.

For acousticians and end-users of SLMs in Australia, the effective tightening of allowable tolerances has resulted in the potential for previously conforming instruments to fail future performance verifications. In particular, it is foreseeable that an SLM in use by an acoustician up to the time of the calibration can be found to fail the verification test and be unusable, even though the actual instrument performance may not have changed since manufacture.

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