Calibration and uncertainty evaluation for sound level meter utilizing calibrator

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Abstract

One of the large industrial needs is the use of sound level meter (SLM) especially in noise monitoring even occupational and/or environmental, the calibration of this sound measuring device is essential during the last decades. The coupler approach is regarded as the most practical to apply of the SLM calibrating techniques required by the standard IEC 61672. In this method some tests have to be accomplished to judge the measurement results. The calibration performed within frequency range of 31.5Hz to 8kHz. The results showed that the calculated uncertainity lies within the order of magnitude between 0.3 - 0.45dB. The purpose of this work to assess and analyses the factors that affect the coupler method of SLM calibration method with their associated uncertainties in accordance with the Guide to the expressions of Uncertainty in Measurement (GUM). Additionally, a case study covered in details for the calibration of this equipment.

Keywords: sound level meter, calibrator, ½" working standard microphone (WS2), Uncertainty.

1 Introduction

The last few decades have seen a considerable increase in the development of acoustic devices based on smart-audio technologies, including wireless networks, storage, data transferring, communication systems, and go green facilities [1, 2]. In recent years, the calibration of acoustical devices including microphones (Ms), sound calibrators (SCs), and (SLMs) has gained popularity in the field of metrology. One of the acoustic devices being produced based on this technology is the SLM, which is frequently used by consumers. It has become essential for manufacturing industries, contractor businesses, research and academic institutions, medical foundations, and private sectors as a handheld device with the primary purpose of monitoring loudness in an occupancy area. According to a World Health Organization study, noise pollution, which affects a sizeable portion of the working population, may be the most frequent health risk at work today[3].Due to the frequent use of SLM, it is strongly advised to perform a corrective check and a calibration for the frequency weighting parameter, which is the main component of this device[4]. The SLM can be calibrated in a number of ways right now, and most often, a government institution or a private calibration laboratory will use free field facilities to do so. However, due to the intricacy of the procedure and business priorities, particularly for the private calibration laboratory, there are no instances of calibration in Egypt that use this approach. The coupler method, which employs a multifunction acoustic calibrator(MFAC) as the portable laboratory instrument, has been introduced[5]. This method is easier to use than the other way, and calibration labs should use it to comply with the industry requirement for SLM calibration, which tends to rise annually. However, this technique is thought to be used at NIS and may be used at private calibration labs., where a comprehensive discussion of the calibration results is required. It is worth mention that acoustics department at NIS has semi-automated and fully automated method for SLM calibration utilizing PULSE B&K 3630 with licensed software type 7763(version 5-DB:5) running it. This method may be discussed in details later. According to ISO 17025 requirements for calibration and testing[6], the uncertainty measurement as a key component of the calibration result needs to be thoroughly assessed and studied. The goal of this study is to calibrate SLM using a coupler in line with the frequency weighting parameter of the IEC standard. The frequency weighting calibration output generated using these standards is then compared to the IEC 61672:1-3 reference value. The degree of freedom, extended uncertainty, and standard uncertainty are only a few of the statistical approximations used to determine the important parameters, along with (GUM). The calibration of this equipment in detail will be discussed as a new point in a case study, and the findings will be assessed in respect to the acceptable ranges.

2 Research Methodology

The A-frequency weighting parameter at the sound pressure level of 94 dB(i.e.one level only performed here for illustration and same steps repeated for second level 114dB) was used in this work as a case study for the uncertainty evaluation of SLM calibration utilising the coupler, where the calibration process and its calculation were applied separately. The calibration was carried out using the system apparatus, which includes a class-2 SLM as a unit under test (UUT) which has no port for input, a reference instrument (Multifunction Acoustic Calibrator type B&K 4226,Denmark). The environmental condition recorded as temperature:22.5^{o}C, relative humidity:48%) and no change in this condition through the experiment. At a frequency range of 31.5 Hz to 8 kHz, the SLM was calibrated for A-frequency weighting and C-frequency weighting. The multifunction acoustic calibrator can give a steady SPL in 1/3 octave steps from 31.5 Hz to 8 kHz in frequency. First, the head of SLM(UUT) is fixed carefully inside the cavity of the coupler, then UUT adjusted to fast time weighting, A-frequency weighting and suitable level range. Calibrator adjusted to generate 94dB sound pressure level at frequency 1kHz, then one turn on the calibrator and measurement begin by reading the output sound pressure level on UUT display and recording it after stabilization process. Then repeat the same steps, but with adjusting calibrator to second frequency which may 500Hz down to 31.5Hz and at each frequency one can read the sound pressure level on UUT. Each time of measurement at single frequency repeated 5times and average values taken. After finishing the low frequency range, one can carry out the measurement steps at the higher frequencies above 1kHz. The second test is called time weighting, in this test the coupler output still on 94dB. The UUT adjusted to suitable range and frequency weighting: A, time weighting: fast. One can take the readings 5 on UUT display 5 times, then UUT adjusted on time weighting: slow and measure the level on UUT. Third test is called level range, in this test the coupler output is still 94dB and the operator select the first suitable range which include 94dB inside it and measure the output level 5 times. Then the second suitable UUT range is selected, if there is multiple range suitable and repeat the same steps. The fourth test is the 10dB output increment, where UUT adjusted to suitable range up to the last coupler output level 114dB. The coupler adjusted to 104dB and 114dB , every time the operator take the reading on the UUT display with the same settings (Freq.Wt.:A, T.Wt.:F). The fifth test is weighting difference (A-C) , where the UUT adjusted one time one A-weighting, the time weighting is: F, the reading taken (the coupler output is 94dB). Then UUT is on C-weighting and measuring this level, thus the difference between both cases can calculated. Figure 1 represents the connection between cavity of acoustic calibrator with the head (microphone and preamplifier) of SLM(UUT).

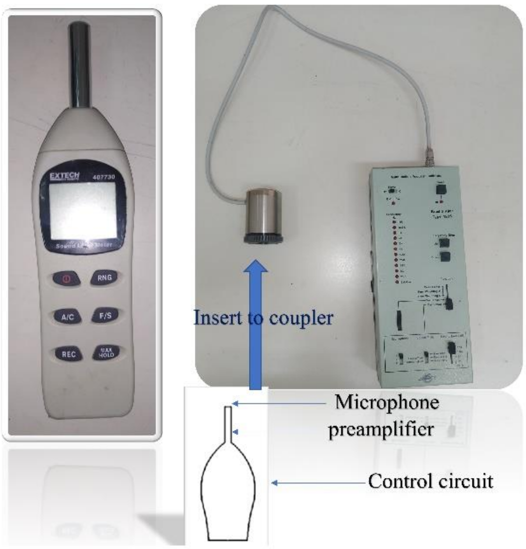


Figure 1: Represent the SLM and multifunction acoustic calibrator and the way for connection between them.

3 Theory and Calculation

Frequency weighting is regarded as the primary parameter that should be used in sound measurement, whether for calibration or measurement. According to international standards IEC 61672[7], it is explicitly described as an electronic filter integrated into a sound level metre that correlates objective measurements with a human subjectivity. As a result, compared to lower and higher frequencies, the human ear is most responsive to sound at frequencies between 500 Hz and 6 kHz[8]. The ability of the acoustic equipment, such as a noise dosimeter or sound level metre, to produce an accurate indicator of the listener actually is crucial when applying sound pressure level measurement. Additionally, frequency weightings carry out this reading by favouring some frequencies over others[9]. A-weighting, C-weighting, and Z-weighting are the three different forms of frequency weightings. The first weighting is frequently used in sound level metres to ensure that the readings are accurate for human hearing. It also covers the entire frequency range of 20 Hz to 20 kHz, making it the most widely used method for measuring sound[10]. As a result, it operates with modifying the indicator of sound pressure level (SPL), which refers to the sensitivity of the human ear. Additionally, this weighting is a necessary component for calculations of the risk of hearing damage. Common abbreviations for the results of sound measurements based on A-weighting are dB(A) or dBA[11]. The sound level metre can be found to have a second weighting that conforms to a human hearing response at high sound pressure levels. Comparatively to the A-weighting, the C-weighting has a greater impact on low-frequency sounds on the human ear, and between 31.5 Hz and 8 kHz, it is practically flat or linear. Peak sound pressure level (SPL) and an impulsive noise measurement are two common uses for it. dB(C) or dBC are standard display formats for the indicator utilising this weighting[12]. The final option is Z-weighting, which determines the actual noise without weighting calculations for the human ear and has a flat frequency response of 8 Hz to 20 kHz (Z for zero). Additionally, it is frequently employed in octave band analysis and the detection of background noise. This weighting's measurements are displayed as dB(Z) or dBZ. For example, the correction curve for both frequency weighting A and C is shown in figure 2**.**

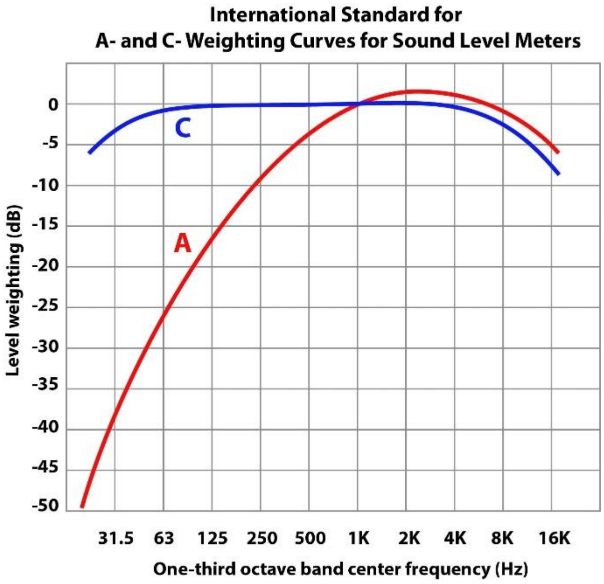


Figure 1: Frequency weighting correction curves of the most used in SLM(A and C-weighting):source: [7].

3.1 Mathematical Expressions and Symbols

It is possible to define the mathematical model of this calibration process, where the difference between the sound pressure level is described. It was determined by a SLM and afterwards described as (L_{uut}) and the multifunction acoustic calibrator's produced (L_{ac}). Additionally, these devices have correction values (δ_{uut}),(δ_{ac}) that depend on frequency that can be derived from the calibrator's calibration results, while for the UUT, these values are typically provided by the manufacturer. The following is the mathematical formula for the SLM calibration [5].

$$\Delta L = (L_{uut} + \delta_{uut}) - (L_{ac} + \delta_{ac}) \qquad (1)$$

In rare circumstances, the manufacturer may not provide the sound level meter's correction values information. Therefore, it can be disregarded in the equation (1). Based on this mathematical model, the use of uncertainty budgets is thus possible.

3.1.1 Uncertainty sources

The two categories of the budget of uncertainty are A-type and B-type. While the latter is the source that can be determined through a scientific judgement or other information that is considered to contribute to the result of measurement or calibration[13], the former is the parameter that can be obtained by applying some measurement series and generally solving with a statistical procedure. In addition to using a mathematical model, there is a more practical way to simplify the calculation of uncertainty budgets, and this may be done by using the fishbone [7], which is seen in (figure 3) in the context of sound level metre calibration using the coupler approach.

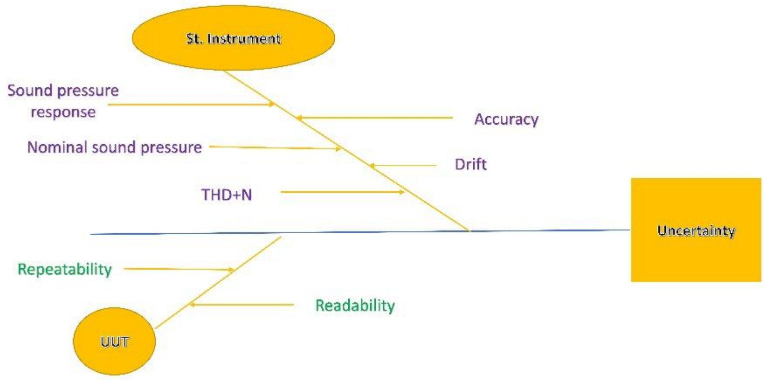


Figure 3 : Fishbone diagram for the uncertainty sources in the SLM calibration utilizing calibrator.

The repeatability and readability of L as measured by the reference instrument, according to the SLM as UUT, make up the component. The first falls under the category of an A-type uncertainty budget. There are five times as many measurement data for L as there are required frequencies. The standard deviation of the relevant data is then determined. In the meantime, the latter is categorised as a budget with B-type of uncertainty. Additionally, it depends on the kind of SLM that is being used; class 1 or class 2 of this portable device which may has a resolution of 0.01 dB, while class 2 has a readability of 0.1 dB. The component of the uncertainty budget for the reference instrument's next parameter, which is represented by a (MFAC), includes calibration of a nominal sound pressure level, drift from usage, sound pressure response, level of accuracy, and total harmonic distortion with noise. This parameter's first mentioned element is included in the B-type of uncertainty budget. It is derived from the calibration results using the laboratory standard microphone as the main reference for the insert voltage method of acoustic measurement. The second component, which is also categorised as a B-type of uncertainty budget, is derived from the measurement findings of an intermediate check that is carried out yearly using the same criteria and procedures as the first component. The manufacturer then provides the final three items for this parameter in the initial certificate and manual, and these items are further categorised as B-type uncertainty budgets.

3.1.2 Uncertainty Evaluation

The standard instrument's repeated measurements of the SLM (repeatability). it can be written as follows: it is achieved by computing the standard deviation ($S_{dev.}$) after obtaining the data serially.

$$S_{dev.} = \sqrt{\frac{1}{N-1}} \sum (L_i - \bar{L}) \qquad (2)$$

where L_i is the measurement of the individual sound pressure level(SPL), $\bar{L}$ is the mean of the measurements, and N is the number of measurement series taken under the same conditions. Thus, (u_1) can be calculated using equation (3) below.

$$u_1 = \frac{S_{dev.}}{\sqrt{N}} \qquad (3)$$

UUT readability based on its resolution, it can be allocated to (u_2), which is as follows:

$$u_2 = \frac{a}{\sqrt{3}} \qquad (4)$$

where $\sqrt{3}$ is a divisor of the square distribution per GUM, and an is a half of the UUT resolution.

The calibration of the reference instrument's nominal SPL, it is derived from the most recent calibration certificate. The confidence level is declared to be 95%, so it should be calculated using a normal distribution with a divisor of 2, and the uncertainty (u_3) calculated as:

$$u_3 = \frac{U_{cer.}}{2} \qquad (5)$$

The reference instrument's drift, as was already indicated, it is derived from the annual check, and neither a statement nor information regarding the used distribution or its confidence level is provided. As a result, the square distribution is the one that should be used for this budget. So, the uncertainty (u_4) can be given as:

$$u_4 = \frac{U_{drift}}{\sqrt{3}} \qquad (6)$$

sound measurement of the standard's pressure response. It can be found in the associated instrument's manual. The square distribution should be used for this component because there is no information available to explain the confidence level. Therefore, (u_5) is given by,

$$u_5 = \frac{U_{resp.}}{\sqrt{3}} \qquad (7)$$

The degree of the reference's accuracy, the same source used for the prior budget is used again. Following that, the uncertainty for this component (u_6) can be determined as follows:

$$u_6 = \frac{U_{acc.}}{\sqrt{3}} \qquad (8)$$

(THD + N) Total harmonic distortion plus noise This is a component(u_7) in calibrating the reference instrument's nominal SPL, and it can be calculated as follows.

$$u_7 = \frac{U_{THD+N}}{2} \qquad (9)$$

Depending on the kind of uncertainty approach being utilised, there is a degree of freedom (v_i). For A-type, it may be computed by subtracting the entire quantity of measurement data (N) by 1. However, according to JCGM and an estimation result from a work that has been published, it should be infinite for the other. Consequently, the following serial writing of these parameters is possible:

$$v_i = N - 1 \;\; for\ type\ A \qquad (10)$$

$$v_i = \infty \;\; for\ type\ B \qquad (11)$$

3.1.3 Combined uncertainty

The following equation can be used to compute the combined uncertainty (u_c):

$$u_c(L) = \sqrt{u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2 + u_6^2 + u_7^2} \qquad (12)$$

3.1.4 Expanded uncertainty

One can calculate the extended uncertainty ($U_{exp.}$) by multiplying the combined uncertainty, for which the confidence level is 95%, by a coverage factor (k). There are also several guidelines for obtaining the k value, such using the t-student table and calculating another parameter known as the effective degree of freedom, or $v_{eff.}$ The other guide can then be used by using the Welch-Satterthwaite formula to calculate the effective degree of freedom, as shown below:

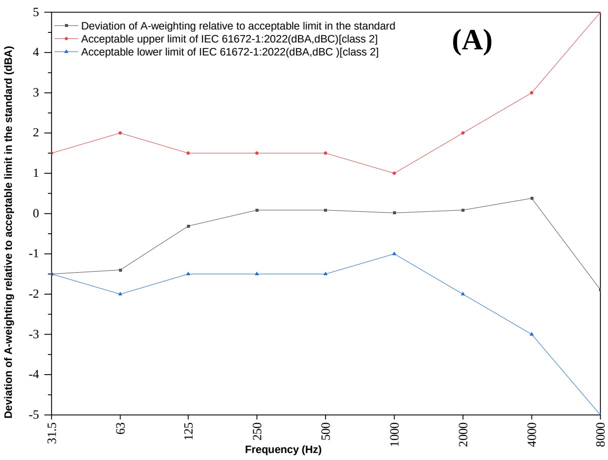
$$\nu_{eff.} = \frac{u_c^4(L)}{\sum_{i=1} \frac{N u_i^4(L)}{\nu_i}} \qquad (13)$$

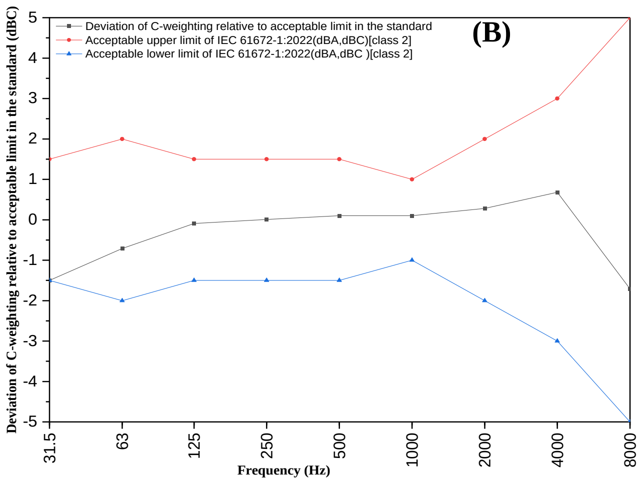
The following formula is used to determine the expanded uncertainty ($U_{exp.}$), then this quantity will be compared to the IEC 61672-1-required acceptance limit value.:

$$U_{exp.}(L) = k * u_c(L) \qquad (14)$$

4 Results and Discussion

Here, we will discuss a case study for calibration of SLM class 2 for a customer using acoustic coupler and explain the results obtained for each test. In addition, the uncertainty of measurement evaluation for this type of calibration will be illustrated with values. **Figure** 4(a,b) displays the measurement outcomes for the level response of the SLM (UUT) during calibration in cases (A and C) frequency weighting parameters was used with a coupler (level:94dB-Frequency:1kHz).





From figure 4 , it is observed that the values of the measured sound pressure levels at the specified 1/3 octave frequencies lies within the standardized acceptable tolerance limits (upper and lower) in both A and C-weightings for class 2 SLM. Here most of deviation differences approximately near zero except at the right and left end range of frequencies(31.5Hz, 8kHz). Errors arises across the entire measuring chain are what produce deviations from the optimum development (microphone, preamplifier, weight filter, detector etc.). The measuring microphone of UUT itself is often responsible for the largest portion of the frequency weight characteristic inaccuracy during measurement. The higher deviation observed at the frame frequencies of work which is 31.5Hz and 8kHz, this trend in many cases recorded in the calibration chart of microphones. Where the sensitivity of microphones decreased to a little bit at the very high and very low frequencies. The effect of the SLM electrical circuits may be responsible for the lower percentage of error. The weighting differences (A-C) at the coupler output of 94dB and frequency 1kHz, is in the order of magnitude of 0.1dB. This small value exists within the acceptable tolerance limit for class 2 SLM which is ±0.2dB. The time weighting test record no deviation between the fast and slow response of UUT, thus the SLM passed this test and the known tolerance limit for this test is ±0.1dB. In the level linearity test, UUT has three ranges in which two of them include 94dB, so after carrying out this test we found that the difference between two ranges in order of magnitude 0.1dB. The tolerance limit for class 2 lies within ±1.1dB, thus UUT is passed in this test and we can go to the next test which is 10dB increment. Where, the acoustic coupler output adjusted at two levels (104 and 114dB) at 1000Hz, the obtained level is 103.8dB and 113.8dB respectively at the stated levels 104 and 114dB. Here the deviation is approximately -0.2dB which lies within acceptable limit of standard which is ±0.5dB for class2.

4.1 Estimation of the measurement uncertainty

The values of the expanded uncertainty for SLM calibration utilizing calibrator at different frequencies is shown in figure (5). It is clear from the figure that the values of uncertainty are higher at the lower and higher frequencies (31.5,4000,8000) Hz while it lies within same order of magnitude ~0.3dB within 63-2000Hz. The reason for increasing uncertainty at certain frequencies may be arises from the higher uncertainty values of the used microphone and its calibration at these frequencies. The obtained uncertainty values are considered to be acceptable for class 2 SLM according IEC 61672. The better resolution of UUT may decrease the uncertainty, if the used calibrator adjusted to 114dB the distortion increases and higher uncertainty recorded.

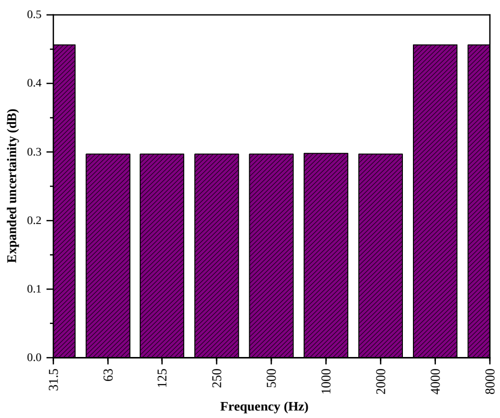


Figure 5: Expanded uncertainty values calculated at different frequencies for class 2 SLM.

5 Conclusions

The calibration of SLM may performed in free field, diffuse field or pressure field, both are complicated methods. In addition, their uncertainty determination is not easy for non-expert in the field of acoustics metrology. NIS acoustics dep. has the ability to carry out the calibration of all types of SLM using pulse labshop running program with license software of a complete system of calibration B&K 3630. This method designed and suitable for special types of SLM which has input socket to connect with this system. In this method multi-function acoustic calibrator utilized during the calibration process. While some of industrial and even environmental places here which need to use SLM may not have high class SLM with the required sockets. They purchased some lower types in degree which may be used for their tasks. So, a method for calibration of this lower types is designed based on IEC61672 standard using the calibrator in their steps. In this method both A and C-weighting measurements performed and two time weighting fast and slow setting adjusted. This method has different tests to be done as illustrated in previous sections. The uncertainty of measurements calculation showed that at the lower and higher frequencies such as 31.5,4000 and 8000Hz the magnitude is 0.46dB which is a little bit higher than other calibration frequencies. The order of magnitude of the uncertainty of the other frequencies lies within 0.3dB. The method with their uncertainties as a case study discussed in details and this may be useful for calibration laboratories in the same field that need to be accredited in the calibration of SLM according ISO-IEC 17025. This method results may be compared with other methods of calibration of SLM.

6 Declarations

6.1 Competing Interests

The authors declare that there is no conflict of interest.

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