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New IEC Standards and Periodic Testing of Sound Level Meters

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ABSTRACT

The publication in October 2006 of the First edition of the IEC Standard 61672-3 Electroacoustics- Sound level meters Part 3: Periodic tests completed the new series of three revised IEC Standards developed to assess the performance of conventional, integrating-averaging and integrating Sound level meters.

This new Standard, along with IEC 61672-1: Specifications for laboratory standard microphones and IEC 61672-2: Pattern evaluation tests, is different from the earlier IEC Standards in many significant ways. The differences are both in the technical requirements as well as in the documentation requirements. The changes are important both for the users of sound level meters and for the laboratories responsible for their pattern approval and periodic verification.

This paper discusses changes in the key technical requirements and differences in the documentation requirements for the testing of sound level meters. It also presents measurement results of periodic tests conducted on three sound level meters: a pre-IEC 61672 manufactured Type 1 model, a post-IEC 61672 manufactured class 1 model and a PC-based model in pre-pattern approval development phase. The results showed that some older sound level meters currently in use may fail to meet the conformance requirements of the new Standards. Measurement uncertainty, accuracy and permissible tolerance related issues are also discussed.

1. INTRODUCTION

Modern sound level meters (SLMs) are simple to operate, however, they incorporate sophisticated signal processing electronic circuitry which is required to display instantaneous sound pressure levels and many other computed parameters. They are either equipped with or have the option to include built-in octave or one-third octave band pass filters using either analogue or digital filtering techniques. Many models have manufacturers' proprietary software installed that allows for further processing and storage of measured sound pressure levels. The use of SLMs for the protection of human hearing under various National Health and Safety Regulations [1] as well as measurements of sound pressure levels to meet other legislative acoustic criteria makes it imperative that the measured values are not only accurate but can also withstand legal scrutiny. According to the International Organization of Legal Metrology (OIML) [2], all instruments used in the surveillance tasks which contribute to the protection and safety of the public and are required by law of government agencies, or of private bodies, in such fields as food, health and drug enforcement should be verified. An uncalibrated SLM is of little use for accurate or traceable measurements unless only relative level information is of interest.

2. INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC) STANDARDS

The IEC 60651 Standard [3] on conventional SLMs that measure time weighted and frequency weighted sound pressure levels and IEC 60804 [4] on integrating-averaging and integrating SLMs that measure time-average and sound exposure levels specified electroacoustic

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requirements for new SLMs. However these two Standards did not consider the issue of periodic tests that should be undertaken at regular intervals to verify the ongoing accuracy of SLMs and carrying out all the tests specified in these two Standards was a time consuming and expensive task. The British Standard BS 7580 [5] specified a limited subset of tests that could be used to verify the accuracy of SLMs at regular intervals. Recommended procedures for regular verifications on SLMs were also given in OIML R58 [6] for SLMs and R88 [7] for integrating-averaging SLMs.

The new IEC 61672: Parts 1–3 Standards [8–10] replace both old SLM Standards and divide the instruments into two performance classes only: class 1 and class 2, compared with the older classifications of Type 0 to Type 3. Class 1 SLMs are precision grade with higher accuracy intended for laboratory or field use with performance tolerances that lie between the old Type 0 and Type 1. Class 2 are general purpose instruments for field use with tolerances which lie between the old Type 1 and Type 2. The specifications for class 1 and class 2 instruments have the same design goals but differ in the applicable tolerance limits (for directional response & frequency weighting), range of operational temperatures and susceptibility to AC and radio-frequency fields. Part 1 provides full specifications for all new SLMs including integrating and integrating-averaging types. Part 2 specifies details of pattern evaluation tests required to establish conformance with the specifications of Part 1. Part 3 specifies a limited set of tests required to verify that the SLM is continuing to perform acceptably in service.

The IEC 61672 Standards require that at least one model of sound calibrator be specified for checking and maintaining the correct indication of the display at the calibration check frequency. If a sound calibrator from a different manufacturer is to be used, the applicable microphone correction data must be known. Characteristics of built-in filters often included in SLMs are not covered in IEC 61672 but are specified in a separate IEC 61260 Standard [11].

3. DIFFERENCES BETWEEN IEC 61672 AND THE OLDER IEC STANDARDS

The new Standards represent a major revision and include a provision for measurement uncertainties in all tolerance limits. The tolerances have been correspondingly increased to some extent to compensate for this but overall the margins available to the manufacturers are lower. The maximum permitted measurement uncertainties are also given to enable manufacturers to calculate the proportion of tolerance available to them for design purposes and to prevent laboratories with greater than maximum allowable measurement uncertainties from undertaking conformance tests.

To conform to the IEC 61672 Standards, the absolute value of the differences between the measured results and the design goal, extended by the actual expanded uncertainties of measurement of the testing laboratory, must lie fully within the specified tolerance limits. This approach, however, causes a fundamental problem: inconsistent conclusions about conformance can be reached depending on how much of the tolerance limit is used by the manufacturer and the magnitude of actual expanded uncertainty of the testing laboratory for either pattern evaluation or periodic tests. In other words, the same measurement result obtained by two different testing laboratories, both meeting the maximum permissible expanded uncertainties, can result in different conformance conclusions depending upon the magnitude of their expanded uncertainties.

The key differences between the new and old Standards for pattern evaluation tests have been described by Meldrum [12], Dowson [13] and Tyler [14] among others and significant changes are summarised below.

3.1. Frequency weighting

Although A-weighting is mandatory for all SLMs, C-weighting is required for class 1 SLMs at least for pattern evaluation, and a new optional Z-weighting has been introduced. Z (or zero) weighting is a replacement for Linear (or Flat) weighting and refers to flat response over the frequency range specified for the SLM with identical tolerances. Tolerances for certain frequency ranges have been tightened to ensure a minimum response in the range 16 Hz to 16 kHz for class 1 SLMs. The B-weighting has been removed as it is no longer used in current noise measurement Standards.

3.2. Directional response

Directional response tests are now required for frequencies from 250 Hz up to 12.5 kHz for class 1 and up to 8 kHz for class 2 instruments with new tolerance limits for 30°, 90° and 150° angles of sound incidence. The aim is to improve the consistency of measurements in different types of sound fields encountered in real situations. These tests are, however, only required for pattern evaluation as they are a characteristic of the SLM design and unlikely to change during the instrument's lifetime.

3.3. Acoustic and frequency response tests

Tests using an acoustic input signal are important as microphones are delicate sensors that require careful handling and acoustic tests are necessary to determine a microphone's performance. As frequency response is often the most likely cause of rejection of a SLM, tests for frequency response for one specified weighting are required to be done both acoustically and electrically. This data can be used to estimate errors introduced acoustically for other weightings by combining with the results of electrical test results. Measurement methods allowed are use of a multi-frequency calibrator, electrostatic actuator, free-field comparison or closed coupler for frequencies less than the lower limiting frequency of the free-field facility.

3.4. Environmental conditions

The reference temperature and relative humidity are now 23 °C and 50 % (previously 20 °C and 65 %) to make them consistent with the specifications of microphones. The operating temperature range of –10 °C to +50 °C now only applies to class 1 SLMs but for class 2 instruments a new limit of 0 °C to +40 °C applies. Similarly, specifications for the influence of temperature have been split and are ± 0.8 dB with ± 0.3 dB included uncertainty for class 1, and ± 1.3 dB with ± 0.3 dB included uncertainty for class 2. Previously the limit was ± 0.5 dB excluding uncertainty for all types which was unrealistic for Type 2 and Type 3 SLMs. Specifications for the influence of relative humidity have been made more stringent for class 1 instruments but relaxed for class 2. For static pressure, a slightly wider pressure range (85 kPa to 108 kPa) and slightly wider tolerances on the deviation from the level at the reference static pressure of ± 0.7 dB and ± 1.0 dB for class 1 and class 2 are allowed. Provision is also made for lower static pressures down to 65 kPa with tolerances on deviations of ± 1.2 dB and ± 1.9 dB for class 1 and class 2 respectively. To reduce testing time, abbreviated tests for combined temperature and humidity at selected combinations are allowed but with tighter tolerances than if done separately. If an SLM fails the combined tests, they must be done separately to establish conformance. These tests are only required for pattern evaluation.

3.5. Peak C response

The tests for peak response in the old IEC 60651 made no reference to frequency weighting so they were often done using A-weighting or Linear weighting rather than C-weighting. The new Standard requires testing of the C-weighted peak level measurement capability of the SLM and, if available, is mandatory for pattern evaluation. This is because C-weighted peak levels rather than Linear levels are now predominantly used for assessing hearing damage risk in work environments. For instance, the National Standard for Occupational Noise (NOHSC 2000) in Australia limits a worker's eight-hour equivalent continuous A-weighted sound pressure level ($L_{Aeq,8h}$) to 85 dB(A) or to a C-weighted peak sound pressure level of 140 dB(C). The Peak level should not be confused with Maximum level as Peak levels are measured without exponential time-weighting and can be several dB higher than the Maximum levels measured using time-weighting F or S with time constants of 125 ms and 1 s respectively.

3.6. Under-range and overload

SLMs now have to indicate under-range and display below the bottom of range is not allowed without a warning flag. The warning flag requirement applies to both displayed values and to stored values. Overload detection has not changed but the tolerances and tests have been tightened.

3.7. Level linearity

Level linearity is the ability to correctly square and form the time-integral of the sound pressure level over a range of input signal levels and SLMs are now required to have at least 60 dB dynamic range. The old Standard only required this value for Type 1 integrating SLMs and reduced it to as little as 15 dB for non-integrating SLMs due to limitations of the available technology at the time. The concept of primary indicator range of IEC 60651 has been removed, however, a reference range must be defined by the manufacturer and all measurement ranges must meet the same tolerances which have been simplified.

3.8. Toneburst response

The specifications for time weighting and integrating-averaging functions have been merged into toneburst response. Time weighting is tested by comparing the indication of the SLM to short pulses with its indication for a continuous signal of the same level and frequency. The time-average sound level (L_{Aeq}) is now specified under response to repeated tonebursts in terms of the difference between the theoretical time-average sound level of a sequence of tonebursts and the time-average sound level of the steady signal of the same level.

3.9. Electromagnetic compatibility

Requirements for limits to radio-frequency emissions and susceptibility of SLMs to static discharges remain unchanged. However, limits for the influence on the SLM by incident RF fields have been made stricter with the field strength increased to 10 V/m over the wider carrier frequency range of 26 MHz to 1 GHz. This is primarily to improve immunity from interference due to increasing use of mobile telephones. These tests are only required for pattern evaluation.

3.10. Time weighting

Impulse or ‘I’ time-weighting has been removed as its results are often unsatisfactory for rating impulsive sounds but is still included as an informative annex.

The new Standard requires a detailed instruction manual that must be available for performing tests and SLMs with no means of inserting electrical signals are unacceptable. For multi channel SLMs, tests of crosstalk are now included and tests on the influence of power supply voltage are also required for pattern evaluation.

Overall the new Standard should result in more consistent measurement values particularly under various field situations, over a wide range of environmental conditions and sound incidence directions. Where limits have been tightened or additional requirements introduced, some older SLMs may fail the tests. The cost of pattern evaluation tests is expected to be higher and tests are more time consuming but this is a one-off cost for each new model.

4. DIFFERENCE BETWEEN PATTERN EVALUATION TESTS AND PERIODIC TESTS

Pattern evaluation tests specified in IEC 61672-2 are more thorough than the periodic tests specified in IEC 61672-3 and include directional response measurements. As the technical requirements for testing in the two Standards are rather complex, actual Standards must be consulted for comparison purposes. Pattern evaluation requires testing at least two SLMs: out of which one is fully tested while the other may be subjected to limited testing at the discretion of the testing laboratory. Pre-requisites for pattern evaluation testing include the availability of a detailed instruction manual containing all information required by Clause 9 of IEC 61672-1, marking in accordance with the requirements of Clause 8 of IEC 61672-1 and provision of many mandatory features listed in Clause 6 of IEC 61672-2.

The tests that are only required for pattern evaluation testing include:

- Environmental tests to determine the influence of pressure, temperature and relative humidity;
- The influence of static discharge on the operation of the SLM;
- The influence of AC power frequency and RF fields;
- RF emissions;
- Directional response;
- Level linearity error at elevated air temperatures;

- Decay time constants for time weightings F and S;
- Verification of all adjustment data to obtain free field levels;
- The influence of power supply voltage.

To demonstrate that a SLM conforms to the specifications of the IEC 61672-3 Standard, it must be subjected to a series of acoustic and electrical tests. Electrical tests are done by replacing the microphone with an electrical signal input device whose impedance loading i.e. capacitance is equivalent to that of the microphone. These tests can check the performance of the microphone amplifier circuit, weighting networks and filters but not the microphone for which acoustic tests are necessary. The complete SLM is also tested over a wide temperature and humidity range specified in the Standard and for its immunity to external radio-frequency radiation. In addition, all configurations (including windscreen and installed optional facilities) stated in the instruction manual as conforming to IEC 61672-1 are required to be tested and self generated noise must be measured for each model of the microphone specified for use with the SLM. For a multi-channel SLM, each channel is separately pattern evaluated. A complying instrument can be issued a pattern approval or conformance certificate and any subsequent change to the instrument would generally require re-testing.

For some electroacoustical performance tests, there are fewer requirements for periodic testing e.g. tests of frequency weightings with acoustical signals are required at only three test frequencies.

Because both frequency response and directional response are influenced not only by the response of the microphone but also the instrument’s case which may cause sound reflections, many SLMs are of similar shape with the microphone mounted on a stalk attached to a tapered body. SLMs with a rectangular box shape with the microphone mounted flush at one end are unlikely to meet directional response requirements of IEC 61672-1. The influence of the body depends strongly on the geometric shape of the SLM, goes through a peak as frequency is increased, and can be as much as 0.4 dB [15]. For PC-based SLMs, the use of long microphone extension cables reduces the influence due to the instrument’s case. Any change of hardware or software will probably require separate pattern approval, i.e. the hardware and software configuration for which pattern approval tests were performed cannot be changed. A change in software may only require the electrical tests to be redone.

Many characteristics of a SLM such as its physical shape and the microphone’s directivity response don’t change with time and, therefore, don’t require periodic tests. However regular verification by periodic testing is required for parameters listed in IEC 61672-3. The maximum interval between periodic verifications is not recommended in the Standard but it is generally set to two years by accreditation bodies. Reverification should be done earlier if the SLM has undergone repair that is likely to affect its performance. Use of a calibrator to check the performance at one frequency is not a substitute for periodic testing although it should be done routinely before and after all acoustic measurements. In reality, many class 2 SLMs are often not periodically tested but such testing is the only means of ensuring that false or incorrect results are not being generated. The IEC 61672-3 Standard requires the same periodic tests for both class 1 and class 2 instruments, but the frequency range to be tested varies depending on the test.

5. TEST SLMS AND TEST EQUIPMENT

The results of periodic tests done on three different models of SLMs are presented here to show the application of the new IEC 61672-3. The three SLMs, designated as SLM 1, SLM 2 and SLM 3, were: a pre-IEC 61672 manufactured Type 1 SLM, a post-IEC 61672 manufactured class 1 SLM and a PC-based SLM designed to meet class 1 requirements but still in the pre-pattern approval development phase. Marking on the SLM 1 included the manufacturer's name and reference to IEC 804-1985 Type 1 but no reference to IEC 61672-1. The reference range for the SLM 1 was 50 dB – 130 dB whereas the SLM 2 and SLM 3 had single reference ranges of 20 dB – 140 dB and 25 dB – 120 dB respectively.

Electrical test signals were generated using a Stanford Research Systems DS360 ultra-low distortion function generator and a HP34401A multimeter was used as the measuring voltmeter. For the indication of SLMs at the calibration check frequency and for acoustic tests of frequency weighting, a calibrated Bruel & Kjaer multifunction acoustic calibrator type 4226 was used. For acoustic and self-generated noise measurements, the NMI anechoic room with a noise floor of less than 15 dB(A) equipped with dedicated free-field frequency response measuring set-up was used. The anechoic room at NMI has a cut-off frequency above 125 Hz so the acoustic frequency response test results at 125 Hz obtained using the multifunction calibrator are reported. It should be noted that manufacturers are required to give pressure to free field corrections appropriate to the microphone(s) specified for the SLM as well as correction data for the effect of the SLM body on a free field sound field which allows the closed coupler method to be used. The use of a suitable dedicated free field test facility obviates the need to apply these corrections. However, they are still required to be documented in the instrument's instruction manual.

6. MEASUREMENT PROCEDURE AND TEST RESULTS

All applicable periodic tests specified in IEC 61672-3 were carried out on the three SLMs in accordance with the requirements of various Clauses of the Standard. Electrical signals for all electrical tests were applied to the SLMs using the DS360 function generator via a 12.5 pF electrical input signal device that closely matched the microphone capacitances in the SLMs of 12.0 pF, 12.4 pF and 12.7 pF. The AC electrical output signals were either taken to the measuring voltmeter or the response of SLMs was read directly from the display. The battery supply voltages were checked before and after the completion of measurements to ensure that it was within the limits stated in the instruction manuals. The measurement procedures used and the results of the periodic tests are discussed in the following sections. The tolerances stated in the tables are for class 1 instruments.

Environmental conditions in the laboratory during all the tests were controlled in the range (23 ± 0.5) °C and (50 ± 15) %RH and the tests were done at ambient atmospheric pressure that was within 100-103 kPa range.

6.1 Indication of the electrical output (IEC 61672-3 Clause 8)

This test is required to confirm that the indications from the electrical output and the corresponding indications on the SLM display are identical within the allowable tolerances. The results of these tests for the SLM 1 and SLM 2 for a change in levels of 20.0 dB are shown in Table 1. The SLM 3 had no AC electrical output facility.

Table 1. Indicated changes on SLM display and electrically measured changes.

SLM Number	Change indicated on display, dB	Change electrically measured, dB	Difference dB	Uncertainty dB	Tolerances, dB (IEC 61672-1, Clause 5.16.3)
SLM 1	20.0	20.00	0	± 0.06	± 0.1
SLM 2	20.0	20.01	0.01	± 0.06	± 0.1
SLM 3	-	-	-	-	-

6.2 Indication at the calibration check frequency (IEC 61672-3 Clause 9)

This test checks the indications of the display of the SLM at a single frequency and level by a sound calibrator. Indications at the calibration check frequency were recorded for the SLMs, with the microphone fitted and the SLM set to the reference range, by exposing the microphone to a calibrated sound pressure level of 94.0 dB at 1000 Hz with the sound calibrator. The indicated readings for the three SLMs were 94.1 dB(A), 94.1 dB(A) and 94.0 dB(A) respectively. No further adjustments were made to the SLMs, however, according to the Standard should an adjustment be deemed necessary it must be done according to the instruction manual and the before and after readings recorded.

6.3 Self-generated noise with microphone installed (IEC 61672-3 Clause 10.1)

This test requires the measurement of the A-weighted self-generated noise, with the microphone installed, at the most sensitive level range. Self-generated noise was measured by placing the SLMs in the anechoic room and averaging ten observations of A-weighted sound pressure levels with time-weighting S taken at random over a 60 s interval. The Standard requires that the measured values not exceed the highest anticipated level of A-weighted self-generated noise stated in the instruction manual for the configuration of SLM tested. If the measured level does exceed the level allowed, the testing laboratory must ensure that the influence of ambient laboratory sound did not influence the measurement by more that 3 dB. The measured values are given in table 2 and did not exceed the limits for self-generated noise provided by the manufacturers' in the instruction manuals.

6.4 Self-generated noise with microphone replaced by the electrical input signal device (IEC 61672-3 Clause 10.2)

This test also measures the self-generated noise but excludes any microphone noise influence and is required for all frequency weightings available in the SLM. Electrical self-generated noise was measured by replacing microphones with appropriate electrical input signal devices terminated with an electrical short circuit and averaging ten sound pressure levels with time-weighting S over a 60 s interval for the different frequency weightings. The results are given in Table 2. The Z-weighting was not implemented in the SLM 3 and SLM 1 had Linear weighting. No tolerances are given for this test in the Standard and the test is intended simply to measure and report the values. If the measured level exceeds the level given in the instruction manual, this does not mean that the performance of the SLM is unacceptable.

Table 2. Self-generated noise with microphone installed and with electrical short circuit.

Frequency weighting	Self-generated noise, dB SLM 1	Self-generated noise, dB SLM 2	Self-generated noise, dB SLM 3
A (microphone installed)	under-range	17.7	19.9
A (short circuit)	under-range	14.7	18.5
C (short circuit)	under-range	17.2	21.0
Z (short circuit)	under-range	24.4	-

6.5 Acoustical signal tests of a frequency weighting (IEC 61672-3 Clause 11)

This acoustic test checks the performance of the microphone and the SLM as a unit at three frequencies (125 Hz, 1000 Hz and either 4000 or 8000 Hz) for frequency weighting C, if available, otherwise for A-weighting. These tests can be done by one of three different methods: using a calibrated multi-frequency calibrator, an electrostatic actuator or in a free field test facility. Because of the availability of an anechoic room and because such measurements automatically include the influence of the instrument's body the free-field method was used. Acoustic tests of C-weighting were done by placing the SLMs (microphone, preamplifier and 2 m long microphone extension cable only for SLM 3) in the anechoic room and measuring the frequency response at 74 dB SPL by comparison with a calibrated reference microphone. The frequency response for C-weighting, relative to 1 kHz, was determined from the differences between the indicated C-weighted sound pressure levels and the actual sound pressure levels. The measurement procedure used provided results that included all four nominated frequencies so their results are given in Table 3.

Table 3. Response to an acoustical signal for frequency weighting C. The numbers in brackets are deviations of the measured results from the expected results.

Frequency Hz	Response dB(C) SLM 1	Response dB(C) SLM 2	Response dB(C) SLM 3	Uncertainty dB	Tolerances, dB (IEC 61672-1, Table 2)
125	0.0 (0.2)	–0.1 (0.1)	0.2 (0.4)	± 0.2	± 1.5
1000	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	± 0.2	± 1.1
4000	–0.8 (0.0)	–0.5 (0.3)	–0.2 (0.6)	± 0.2	± 1.6
8000	–3.0 (0.0)	–2.8 (0.2)	–2.4 (0.6)	± 0.4	+2.1/–3.1

6.6 Electrical signal tests of frequency weightings (IEC 61672-3 Clause 12)

In contrast to acoustical tests which are required for a single frequency weighting, electrical tests are required for checking the performance of different frequency weightings available in the SLMs. For class 1 instruments, the Standard requires measurements at nominal octave intervals from 63 Hz to 16 kHz. For these tests, steady sinusoidal electrical signals of amplitude sufficient to give an indication 45 dB below the upper linear limit at 1000 Hz were inserted into the SLMs through the electrical input signal device. The indications of the SLMs were recorded by varying the frequency of the input signal and, at the same time, adjusting the input signal level to compensate for the design-goal attenuation given in IEC 61672-1 for the relevant frequency weightings. The results for the response to electrical signals for frequency weightings A, C and Z (or Linear) are shown in Tables 4, 5 and 6. The Z-weighting was not implemented in SLM 3.

Table 4. Response to an electrical signal for frequency weighting A.

Frequency Hz	Response dB(A) SLM 1	Response dB(A) SLM 2	Response dB(A) SLM 3	Uncertainty dB	Tolerances, dB (IEC 61672-1 Table 1)
63	–0.2	0.0	–0.2	± 0.1	± 1.5
125	–0.2	–0.1	–0.2	± 0.1	± 1.5
250	–0.1	–0.1	–0.1	± 0.1	± 1.4
500	–0.1	–0.1	–0.1	± 0.1	± 1.4
1000	0.0	0.0	0.0	± 0.1	± 1.1
2000	0.0	0.0	0.0	± 0.1	± 1.6
4000	0.1	0.0	0.0	± 0.1	± 1.6
8000	0.0	0.0	–0.1	± 0.1	+2.1/–3.1
16000	0.0	–1.0	–2.9	± 0.1	+3.5/–17

Table 5. Response to an electrical signal for frequency weighting C.

Frequency Hz	Response dB(C) SLM 1	Response dB(C) SLM 2	Response dB(C) SLM 3	Uncertainty dB	Tolerances, dB (IEC 61672-1 Table 1)
63	0.0	0.0	–0.2	± 0.1	± 1.5
125	0.0	0.0	–0.1	± 0.1	± 1.5
250	0.0	0.0	–0.1	± 0.1	± 1.4
500	0.0	0.0	0.0	± 0.1	± 1.4
1000	0.0	0.0	0	± 0.1	± 1.1
2000	0.0	0.0	0.0	± 0.1	± 1.6
4000	0.0	–0.1	0.0	± 0.1	± 1.6
8000	0.0	0.0	–0.1	± 0.1	+2.1/-3.1
16000	0.0	–1.0	–3.0	± 0.1	+3.5/-17

Table 6. Response to an electrical signal for frequency weighting Z (or Linear).

Frequency Hz	Response dB (Linear) SLM 1	Response dB(Z) SLM 2	Response dB(Z) SLM 3	Uncertainty dB	Tolerances, dB (IEC 61672-1 Table 1)
63	0.0	0.0	-	± 0.1	± 1.5

125	0.0	0.0	-	± 0.1	± 1.5
250	0.0	0.0	-	± 0.1	± 1.4
500	–0.1	0.0	-	± 0.1	± 1.4
1000	0.0	0.0	-	± 0.1	± 1.1
2000	0.0	0.0	-	± 0.1	± 1.6
4000	0.0	0.0	-	± 0.1	± 1.6
8000	0.1	0.0	-	± 0.1	+2.1/–3.1
16000	–0.2	0.0	-	± 0.1	+3.5/–17

6.7 Frequency and time weightings at 1 kHz (IEC 61672-3 Clause 13)

These electrical tests are used to check the performance of C-weighting, Z-weighting and L_{Aeq} for time weightings F and S at a frequency of 1 kHz. The tests were done using a steady sinusoidal electrical signal of 1 kHz whose amplitude was adjusted to give an indication of 94.0 dB(A) on the SLMs. The indications of the SLMs were recorded for the various frequency and time weighting settings are given in Table 7. Time weighting S and frequency weighting Z were not implemented in SLM 3.

Table 7. Indications of the SLMs for various frequency and time weightings.

Frequency and time weighting	Indicated level, dB SLM 1	Indicated level, dB SLM 2	Indicated level, dB SLM 3	Uncertainty dB	Tolerances, dB (IEC 61672-1 Table 1)
Time weighting F:					
A	94.0	94.0	94.0	± 0.1	± 0.4
C	94.0	94.0	94.0	± 0.1	± 0.4
Linear or Z	94.0	94.0	-	± 0.1	± 0.4
Time weighting S:					
A	94.0	94.0	-	± 0.1	± 0.4
L_{Aeq}	93.8	94.0	94.0	± 0.1	± 0.3

6.8 Level linearity on the reference level range (IEC 61672-3 Clause 14)

Level linearity tests are required to check the linearity of the display of the SLM with changes in sound pressure levels. For instruments with different level ranges, separate linearity tests are required for checking the errors introduced by the level range control (see Sections 6.9 and 6.10). Level linearity tests on the reference level range are performed using steady sinusoidal electrical signals of 8 kHz with the SLMs set to frequency weighting A and time weighting S. The amplitude of the signal, initially set to give an indication at the reference level of 94 dB in each case, is increased in 5 dB steps up to within 5 dB of the upper limit of the linear operating range. The signal is then increased in 1 dB steps until, but not including the first indication of overload. The tests are then continued, again starting from the 94 dB level with the signal decreasing in 5 dB steps down to within 5 dB of the specified lower limit. The signal is then decreased in 1 dB steps down to, but not including the first indication of under-range or the lower limit of the linear operating range. The results of the level linearity tests are given in Table 8.

Table 8. Level linearity of SLMs on the reference level range.

Input signal level dB(A)	Indicated level, dB(A) SLM 1	Indicated level, dB(A) SLM 2	Indicated level, dB(A) SLM 3	Uncertainty dB	Tolerances, dB (IEC 61672-1, Clause 5.5.5)
138.0	-	138.0	-	± 0.1	± 1.1
137.0	-	137.0	-	± 0.1	± 1.1
136.0	-	136.0	-	± 0.1	± 1.1
135.0	-	135.1	-	± 0.1	± 1.1
134.0	-	134.0	-	± 0.1	± 1.1
130.0	130.0	-	-	± 0.1	± 1.1
129.0	129.0	129.0	-	± 0.1	± 1.1
124.0	124.0	124.0	-	± 0.1	± 1.1
120.0	-	-	120.0	± 0.1	± 1.1
119.0	119.0	119.0	119.0	± 0.1	± 1.1
118.0	-	-	118.0	± 0.1	± 1.1
117.0	-	-	117.0	± 0.1	± 1.1
116.0	-	-	116.0	± 0.1	± 1.1
115.0	-	-	115.1	± 0.1	± 1.1
114.0	114.1	114.0	114.0	± 0.1	± 1.1
109.0	109.1	109.0	109.0	± 0.1	± 1.1
104.0	104.0	104.0	104.0	± 0.1	± 1.1
99.0	99.0	99.0	99.1	± 0.1	± 1.1
94.0	94.0	94.0	94.0	± 0.1	± 1.1
89.0	89.0	89.0	89.1	± 0.1	± 1.1
84.0	84.0	84.0	84.1	± 0.1	± 1.1
79.0	79.0	79.0	79.1	± 0.1	± 1.1
74.0	74.0	74.0	74.1	± 0.1	± 1.1
69.0	69.0	69.0	69.0	± 0.1	± 1.1
64.0	63.9	64.0	64.0	± 0.1	± 1.1
59.0	59.0	58.9	59.0	± 0.1	± 1.1
54.0	53.9	54.0	54.1	± 0.1	± 1.1
53.0	53.0	-	-	± 0.1	± 1.1
52.0	52.0	-	-	± 0.1	± 1.1
51.0	51.0	-	-	± 0.1	± 1.1
50.0	50.0	-	-	± 0.1	± 1.1
49.0	-	49.0	49.1	± 0.1	± 1.1
44.0	-	44.0	44.0	± 0.1	± 1.1
39.0	-	39.1	39.1	± 0.1	± 1.1
34.0	-	34.1	34.2	± 0.1	± 1.1
29.0	-	29.2	29.3	± 0.1	± 1.1
28.0	-	28.1	28.5	± 0.1	± 1.1
27.0	-	27.1	27.5	± 0.1	± 1.1
26.0	-	26.5	26.6	± 0.1	± 1.1
25.0	-	25.3	25.7	± 0.1	± 1.1
24.0	-	24.4	-	± 0.1	± 1.1
23.0	-	23.7	-	± 0.1	± 1.1
22.0	-	22.6	-	± 0.1	± 1.1
21.0	-	22.0	-	± 0.1	± 1.1

6.9 Level linearity including the level range control at the reference sound pressure level (IEC 61672-3 Clause 15.2)

These tests were done on SLM 1 only because both SLM 2 and SLM 3 had a single level range so the tests are not applicable. The SLM is set to its reference range (50 dB – 130 dB), frequency weighting A and time weighting F, and a 1 kHz sinusoidal electrical signal applied with amplitude set to give an indication of 94.0 dB (reference level) on the display. With the signal kept constant, the range settings of the SLM were changed and the indications of the display recorded. The results of these tests are given in Table 9.

Table 9. Results of level linearity test results, including level range control, at reference sound pressure level.

SLM range setting, dB	Indicated level, dB(A) SLM 1	Indicated level, dB(A) SLM 2	Indicated level, dB(A) SLM 3	Tolerances, dB (IEC 61672-1, Clause 5.5.5)
50 - 130	94.0	-	-	± 1.1
60 - 140	94.0	-	-	± 1.1
40 - 120	94.0	-	-	± 1.1
30 - 110	94.0	-	-	± 1.1
20 - 100	94.0	-	-	± 1.1

6.10 Level linearity including the level range control at a sound pressure level 5 dB below the upper limit for the range (IEC 61672-3 Clause 15.4).

These tests were also done on SLM 1 only because both SLM 2 and SLM 3 had a single level range so the tests were not applicable. The SLM is set to the reference range (50 dB – 130 dB), frequency weighting A and time weighting F, and a 1 kHz sinusoidal electrical signal applied with amplitude set to give an indication on the meter which is 5 dB below the upper linear limit of the reference range. With the signal kept constant, the range settings of the meter were changed and the indications of the display recorded. The results are given in Table 10.

Table 10. Level linearity, including level range control, at 5 dB below the upper limit.

SLM range setting, dB	Test level, dB(A)	Indicated level, dB(A) SLM 1	Indicated level, dB(A) SLM 2	Indicated level, dB(A) SLM 3	Tolerances, dB (IEC 61672-1, Clause 5.5.5)
50 - 130	125.0	125.0	-	-	± 1.1
60 - 140	135.0	135.0	-	-	± 1.1
40 - 120	115.0	115.0	-	-	± 1.1
30 - 110	105.0	105.0	-	-	± 1.1
20 - 100	95.0	95.0	-	-	± 1.1

6.11 Toneburst response (IEC 61672-3 Clause 16)

The toneburst response tests are required for checking the response of the SLMs to short duration signals. The test signals are 4 kHz toneburst, extracted from steady 4 kHz sinusoidal electrical signals with the SLM set to frequency weighting A. For these tests, the SLMs were set to frequency weighting A and on the reference range (if applicable), and the level of continuous signal was adjusted to give an indication of 3 dB(A) below the upper linear limit. The SLMs were then exposed to tonebursts of varying durations but of the same amplitude and frequency as the continuous signal, and the maximum indicated sound pressure levels by the SLMs recorded. For SLM 3 which did not directly indicate sound exposure levels (L_{AE}), the L_{AE} was calculated from indicated L_{Aeq} values using the equation:

$$L_{AE} = L_{Aeq} + 10\, log_{10}(T/T_0) \quad (1)$$

where T is the time interval for measurement and T_0 is 1 s.

The SLMs responses to tonebursts are shown in Table 11. SLM 3 did not have time weighting S implemented.

Table 11. Toneburst response of SLMs for time weightings F and S and for L_{AE}. The numbers in brackets are deviations of the measured results from the expected results.

Burst duration	No. of cycles in burst	Indicated level, dB(A) SLM 1	Indicated level, dB(A) SLM 2	Indicated level, dB(A) SLM 3	Uncertainty dB	Tolerances, dB (IEC 61672-1, Table 3)
Continuous		127.0	137.0	117.0		
Time weighting F:						
200 ms	800	125.9 (–0.1)	135.9 (–0.1)	116.0 (0.0)	± 0.2	± 0.8
2 ms	8	108.7 (–0.3)	119.0 (–0.1)	98.8 (-0.2)	± 0.2	+1.3/–1.8
0.25 ms	1	98.9 (–1.1)	109.8 (–0.2)	89.9 (-0.1)	± 0.2	+1.3/–3.3
Time weighting S:						
200 ms	800	119.7 (0.1)	129.9 (0.3)	-	± 0.2	± 0.8
2 ms	8	99.7 (–0.3)	110.3 (0.3)	-	± 0.2	+1.3/–1.8
Sound Exposure Level (L_{AE}):						
200 ms	800	119.8 (–0.2)	129.9 (–0.1)	-	± 0.2	± 0.8
2 ms	8	99.2 (–0.8)	109.9 (–0.1)	91.0 (1.0)*	± 0.2	+1.3/–1.8
0.25 ms	1	89.3 (–1.7)	100.8 (–0.2)	81.8 (0.8)*	± 0.2	+1.3/–3.3

***** Calculated from measured L_{Aeq} levels.

6.12 Peak C sound level (IEC 61672-3 Clause 17)

The capability of SLMs to correctly measure Peak C sound levels, if available, is tested by measuring response to a single complete cycle of frequency 8 kHz and for positive and negative half-cycles of 500 Hz. Peak C responses were determined by setting the SLMs to frequency weighting C and time weighting F. A steady 8 kHz sinusoidal electrical signal with amplitude set to give an indication on the meter of 8 dB below the upper limit for the peak level range was applied as continuous signal. The continuous signal was then replaced with a signal of one complete cycle of frequency 8 kHz and the peak C response of SLMs recorded. The signal generator was then set to a 500 Hz continuous sinusoidal electrical signal of 8 dB below the upper limit for the peak level range. The continuous signal was then replaced with a signal of 500 Hz of positive half-cycles and negative half-cycles and the peak C response of SLMs recorded. The activation of the overload indicator was also monitored to check that no overload condition occurred. Neither SLM 1 nor SLM 2 recorded an overload condition.

The results of the Peak C-weighted sound level tests on SLM 1 and SLM 2 are given in Table 12. SLM 3 did not have the Peak C measurement capability implemented.

Table 12. Peak C sound level response and overload activation. The numbers in brackets are deviations of the measured results from the expected results.

Peak C response	Indicated level, dB(C) SLM 1	Indicated level, dB(C) SLM 2	Uncertainty dB	Tolerances, dB (IEC 61672-1, Table 4)
Steady signal level	132.0	132.0		
1 cycle, 8 kHz	131.4 (–4.0)	135.5 (0.1)	± 0.2	± 2.4
Positive half-cycle, 500 Hz	132.5 (–1.9)	134.1 (–0.3)	± 0.2	± 1.4
Negative half-cycle, 500 Hz	132.6 (–1.8)	134.1 (–0.3)	± 0.2	± 1.4

It is worth mentioning here that there seems to be an inconsistency between IEC 61672-1 and IEC 61672-2 in relation to Peak C sound levels. While Clause 17 in IEC 61672-2 states that Peak C shall be tested, the IEC 61672-1 states that the SLMs may have Peak C capability i.e. the peak C capability is not mandatory. Adding the words ‘if available’ in IEC 61672-2 can remove this ambiguity.

6.13 Overload indication (IEC 61672-3 Clause 18)

The tests of overload indication are required for SLMs capable of displaying time-average sound levels. The electrical test signal required is a 4 kHz steady input signal adjusted to produce a L_{Aeq} indication 1 dB below the upper limit of the linear operating range and positive and negative half cycles extracted from the steady signals. The specified test signals were applied to the SLMs and the amplitude increased initially in steps of 0.5 dB and then in 0.1 dB steps until the first indication of overload for the positive half cycle. This measurement sequence was repeated for the negative half cycles. It was also confirmed that the overload indicator latches on when an overload condition occurs as required in the Standard and all three SLMs were found to fulfil the latching requirement. The results of the overload indication tests are given in Table 13.

Table 13. Levels for overload indication for positive and negative half-cycles.

SLM Number	Level at overload indication, dB (Positive half-cycle)	Level at overload indication, dB (Negative half-cycle)	Difference dB	Uncertainty dB	Tolerance, dB (IEC 61672-1, Clause 5.10.3)
SLM 1	142.4	142.8	–0.4	± 0.1	± 1.8
SLM 2	143.9	143.4	0.5	± 0.1	± 1.8
SLM 3	123.9	123.5	0.4	± 0.1	± 1.8

7. DISCUSSION OF RESULTS

To compare measured values with the allowable tolerances, the measurement uncertainties have to be included. The measurement uncertainties include uncertainty in obtaining the correct signal at the SLM input, uncertainty in reading the SLM response, uncertainty in burst and time durations for time-averaged quantities and repeatability components. All SLMs had a display resolution of 0.1 dB so the uncertainty due to display resolution can be taken as 0.05 dB semi-range with a rectangular distribution. For electrical tests, resolution is the major contributor to uncertainty and uncertainty components due to other factors such as signal generator frequency accuracy, instability of signal amplitude, uncertainty of burst duration and non-zero signal during the off period between bursts are relatively small. Practical quoted expanded uncertainties for electrical tests are in the range ± 0.1 dB to ± 0.2 dB. For acoustic tests in the anechoic room, the expanded uncertainties are estimated to be ± 0.2 dB except for 8000 Hz where an uncertainty of ± 0.4 dB applies. For measurements using the calibrator, the uncertainty of the SPL generated by the calibrator is estimated to be ± 0.07 dB at 1 kHz. These uncertainties are all well below the maximum expanded uncertainties of measurements in IEC 61672-1 Annex A allowed to testing laboratories for undertaking conformance testing.

The results of acoustic tests and electrical tests showed that the differences between the measured values and the design goal, extended by the actual expanded uncertainties of measurements, are within the IEC 61672-1 class 1 tolerances for all three SLMs investigated except for the L_{Cpeak} parameter for SLM 1 which was found to be outside the tolerances given in Table 4 of IEC 61672-1. As mentioned earlier, this SLM was designed to pre-IEC 61672 requirements and did not undergo the pattern evaluation tests specified in IEC 61672-2 which include L_{Cpeak} measurements. This suggests that some of the older SLM models currently in use may not pass all the tests of IEC 61672-2.

8. UNCERTAINTIES IN USING SLMs

A major source of uncertainty in using a SLM is reflections due to the presence of the observer which can be eliminated by monitoring the SLM remotely via the AC output. For measurements without windscreen, accuracy expected by using class 1 and class 2 instruments (ignoring environmental effects) will depend on the spectrum of sound, the nature of the sound field and the measurement parameter of interest, and can be estimated by examining standard uncertainties using allowable tolerances minus the maximum allowable test laboratory uncertainties given in IEC 61672-1. Table 14 shows various possible uncertainty components and the combined standard uncertainty (assuming no correlation between the components) based on these factors.

Table 14. Standard uncertainties using allowable tolerances minus test laboratory tolerances given in IEC 61672-1.

SLM class	Frequency weighting dB	Directional response dB	Level linearity dB	Toneburst response dB	Calibrator (IEC 61672) dB	Supply voltage dB	Combined standard uncertainty, dB
Class 1	0.5	0.5	0.4	0.25	0.125	0.05	0.9
Class 2	0.9	1.0	0.55	0.5	0.2	0.1	1.6

The standard uncertainty for carrying out practical A-weighted SPL measurements with a class 1 SLM, using statistical analysis of measured data on 22 different SLMs from 9 manufacturers, has been estimated to be ± 0.4 dB with main contributions from time-weighting, RMS detector and linearity [16]. The level linearity uncertainty can be minimised by choosing the same indicator range as that used when the sound calibrator was applied, or by using a SLM with a single large dynamic range that are now available such as SLM 2 and SLM 3 used in this work.

When measuring low SPLs, the uncertainties due to self-generated noise or residual noise (sound left after removal of specific sound under consideration) should not be ignored and will depend on measurement parameter, the measured difference between total and residual sound levels and their uncertainties.

9. SUGGESTIONS FOR FURTHER WORK

The new IEC 61672-1 does not include tests of the effects of mechanical vibrations on the performance of SLMs. OIML R88 provides this guidance by recommending testing with sinusoidal RMS acceleration of 1 m/s^2 in the frequency range 20 Hz to 1 kHz.

Accuracy of data logging capabilities of SLMs with time is not verified although this feature is often sought by users and is available in many instruments. Procedures for calibration of SLMs equipped with fixed combinations of microphone and preamplifier also need to be developed.

Guidelines for estimating the contributions to uncertainty in the measurement of a SPL using a conforming SLM need to be developed i.e. overall uncertainty expected from measurements made using a class 1 or class 2 SLM that conforms to IEC 61672-1. The uncertainty attributable to the use of the SLM would depend on whether A-weighting, C-weighting or Z-weighting is used and the spectrum of sound but, in many practical situations, it would be small relative to uncertainties due to environmental factors and sound reflections from nearby surfaces. Although many SLMs also measure percentile levels, tests of this parameter are not included in the new IEC 61672 Standards and many different methods have been employed to derive the percentile levels.

The new Z weighting does not cover frequencies below 10 Hz and above 20 kHz, and SLMs set to this weighting may yield different results on noise sources containing these low and/or high frequency components depending on the SLMs design at these frequencies.

10. CONCLUSIONS

Results of periodic tests done on three SLMs confirmed that the periodic tests in accordance with IEC 61672-3: 2006 can be successfully undertaken on different types of SLMs including pre-IEC 61672 manufactured models and PC-based models. The expanded measurement uncertainties allowed to testing laboratories to test conformance of SLMs to the IEC 61672

Standards are realistic and easily achievable with good quality instrumentation. The results of measurements have shown that some older SLMs may not conform to all of the specifications of IEC 61672-1, particularly new requirements such as L_{Cpeak} measurement capability. For the design of new SLMs, manufacturers must take into account all pattern evaluation tests that are required and the maximum tolerances available for the design and manufacture if they are to ensure that their SLMs conform to the requirements of the IEC 61672 Standards when tested.

11. REFERENCES

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