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Sound Exposure Meter: Periodic Test Performance Comparison Based on Current Standards

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ABSTRACT

In the world of acoustic metrology, one of the most underestimated equipment is the sound exposure meter, widely known as noise dosimeter. Proof of that is the thoroughly different nature of the two main standards for designing and testing them, namely, the IEC 61252 and ANSI S1.25, that are both aged and have totally different approaches to the equipment functions and even to its circuits. This leads to a challenging situation in contexts where both standards are accepted, once a given sound exposure meter could meet the test tolerances of one of those standards and fail to do so with the other. A worldwide lining up concerning noise dosimeters is expected through the IEC efforts by the PWI 29-40 ED1 project from TC 29, that proposes a revision of the IEC 61252 standard. In this scenario, information about the current periodic test performance found when sound exposure meters are tested by the two most influential standards available, including the differences of those tests, could be a valuable asset for pondering what should be required of them in the future. For those reasons, this work intends to compare the periodic test results by both standards for some of today's available equipment.

Keywords: Sound exposure meter, noise dosimeter, periodic test, IEC 61252, ANSI S1.25
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1. INTRODUCTION

Sound exposure meters are personal use instruments that, when attached with their microphones close to the ear region, follow workers on their journey to integrate acoustical energy. The result of this mathematical operation is paramount to estimate occupational deafness' risk. This operation is proceeded by integrating the sound pressure square. Subsequently, the energy accumulated on the worker's journey is compared to maximum limits stated on different legislation. This approach is adopted by IEC 61252. There are countries, however, that adopt another kind of parameter to estimate deafness risk. This is the case for the USA and Brazil, that adopted the ANSI S1.25 standard. According to this, it is necessary to calculate dose values (%Dose) and those are compared to certain tolerance limits. This is the reason why that equipment is also commonly known as noise dosimeter.

Focusing on constructive block diagrams present on those standards, both electronic circuits and mathematical logics are different on them. According to IEC 61252, the microphone's output signal is pre amplified and frequency weighted. After that, squaring and integration is proceeded. Naturally, energy will double every 3 dB step, hence, it will also double deafness risk. On the other hand, dose calculation is based on A weighted energy values. Two parameters are required for that: Criterion Level (CR) and Exchange Rate (Q), that is the risk doubling factor. This weighted integration differs from the former, once it allows to stablish a customized criterium for deafness risk, as instance, such as one that doubles its value every 5 dB.

Countries in which regulation stablishes tolerance limits in Pa^2h will give priority to IEC 61252 adoption. On the contrary, those countries that stablish tolerance limits in %Dose will give ANSI S1.25 priority. It is important to notice that IEC 61252 isn't suitable for countries that adopt a doubling factor different than 3 dB, whereas ANSI S1.25 also considers the case for Q=3.

Currently, IEC 61252 had entered on the revision schedule of TC 29, but works paused for information gathering. Brazil had sought to contribute in this process by elaborating a document through a work group of ABNT (Brazilian Technical Standards Association), which contains observations concerning the revision proposal. It is good to mention that Brazil is a full member of IEC TC-29. At a first glance, this revision seems to approximate IEC 61252 project to IEC 61672 structure and content (i.e. its three-part division). There are very positive contributions in this process, for instance, regarding pattern evaluation, that will certainly add reliability to noise dosimeter projects. Today, market counts solely on self-stated conformity, which, unfortunately is not always confirmed by periodic tests.

Regarding countries that adopt Q=3, such an approximation to IEC 61672 is very appropriate. Specifications contained on part 1 and periodic tests contained on part 3 make sense for a sound exposure meter that integrates sound pressure square. Therefore, it is possible to approach sound exposure meters as a specific case of sound level meters, having customized physical and constructive characteristics, intended to meet occupational environment demands.

However, if IEC 61252 revision seeks to have an international outreach, as it would be expected, some remarks are relevant to be made. First, a sound exposure meter is always attached to the worker's body, hence, assuming free-field conditions does not seem to be the best approach, as revision had also mentioned. In-factory environments usually have conditions that are closer to a random incidence approximation. Actually, ANSI S1.25 specifies this same sound field for noise dosimeters. It also has to be considered that the microphone is attached 2 or 3 cm away from the workers body and perhaps it is pressure-field the best approximation for real measuring conditions. The standard could make compulsory for manufacturers to inform correction data from pressure field to the sound field stablished on this new revised IEC 61252. Even though discussions about the appropriate sound field will not be addressed on this work, it is a topic that should be carefully considered. Sound exposure meters usually have projects that aim a lower cost, but this should not be achieved on the expense of a lack of control concerning fulfilling tolerances.

Another point is that the revision of IEC 61252 does not contemplate countries which adopt ANSI S1.25 and use an exchange rate different than Q=3. In those cases, deafness risk estimation is defined by work legislation through tolerance limits. In that sense, it would be recommended that IEC 61252 revision would be hybrid in some regard, including both cases.

A hybrid standard would not impact manufacturers significantly, once most models declare conformity by both standards, seeking to improve their selling everywhere. Naturally, it does not mean that self-declared conformity is a sufficient evidence for actual conformity by neither standard. This hybrid standard would have to consider both energy measures in Pa^2h and dose in %Dose. It should also consider differences between those standards, both on their constructive blocks and their periodic testing signals. For instance, energy integration by IEC 61252 does not consider time weightings and other parameters that are contemplated by ANSI S1.25 for noise dose determinations. This is concept does not exist in the IEC 61672-1 context.

On the present work, global conformity declaration regarding some sound exposure meters of different manufacturers and models will be presented, each one tested by both current standards. The contrast between self-declared conformity and actual calibration results will be analyzed. It would also be considered if conformity by one of those standards assures conformity to the other and vice-versa. The calibrations were proceeded Calilab, the calibration laboratory of Total Safety, that has ISO 17025 accreditation with suitable scope for those calibrations since 2008 and has more than 6.500 noise dosimeter calibrations in its database. The results, however, illustrate the typical performance of a given model and not individual results, if not stated otherwise.

2. NOISE DOSIMETER STANDARDS SIDE BY SIDE

Determination of acoustic energy (E) is equally defined both on IEC 61252 and IEC 61672-1, according to equation 1:

$$E = \int_0^T P_A^2 dt \qquad \text{Equation 1}$$

where P_A is the sound pressure A weighted.

Dose determination for a given doubling factor (Q) is given by equation 2:

$$Dose(Q) = \frac{100}{T_c} \int_0^T 10^{[(L-L_c)/q]} dt \qquad \text{Equation 2}$$

where q = Q/log 2, for Q = 4, 5 or 6 (depending on country legislation), L is the sound level, that can be time weighted (L_F ou L_S), and Lc is the reference criterium in dB.

Determining dose levels allows to stablish tolerance limits using doubling risk factors different than 3 dB. Brazilian work legislation defines exposure limits for insalubrity effects using CR = 85 and Q = 5, as seen in Table 1:

Table 1 – Sample of the tolerance limits table for continuous or intermittent noise according to Brazilian legislation

Noise level, A weighted (dB)	Maximum allowable daily exposure
85	8 hours
90	4 hours
95	2 hours
100	1 hour
105	30 minutes
110	15 minutes
115	7 minutes

This deafness risk measurement criterium cannot be evaluated using IEC 61252, once that standard only contemplates Q = 3 doubling factor and does not considers time weighted sound levels. The USA legislation is neither contemplated by the IEC standard. Those differences can be found on Table 2, that shows the main electrical periodic tests for each standard.

Table 2 – Most relevant electrical tests by each standard

IEC 61252 (1993)	**ANSI S1.25 (1991)**
Linearity	Linearity
Frequency Weighting A	Frequency Weighting A and C
Response to short-duration signals	Squaring, Averaging, and Exponential Circuit
Response to unipolar pulses	Exponent Circuit and Integrator

Linearity and frequency weighting tests are basically the same and there is no need to spend time on them. It is quite clear that a project failure on the frequency weighting circuit will be revealed by using any of both standards on its test. However, differences could appear due to range specifications, 20 Hz to 10 kHz on ANSI S1.25 and 63 Hz to 8 kHz on IEC 61252.

The "response to unipolar pulses" test by IEC 61252 is proceeded by means of a sequence of rectangular pulses, with positive and negative transient. Those signals require generators with higher sample rates. On the other hand, IEC 61672-3 avoided those signals and limited itself to using sinusoidal signals. ANSI S1.25 does not include rectangular signals, neither positive and negative transients.

The "response to short-duration signal" test of IEC 61252 (1993) is similar to the Leq test of IEC 60804. It consists in using tone bursts with DC signal alternations. The bursts width and amplitude are defined on Annex B (B4), accompanied by expected values and tolerances. The test allows to identify efficacy of energy integration. This proceeding has no major difficulties and could be easily exchanged by IEC 61672-3 signals, considering IEC 61252 revision. Regarding integration performance, this standard includes no other tests.

If one looks for an equivalent test to this last on ANSI S1.25, there will be two tests instead of one: "Squaring, Averaging, and Exponential Circuit" and "Exponent Circuit and Integrator". The first of them uses short-duration tone bursts, while the second, long-time tone bursts. The last verifies time integration capacity, providing a certain kind of stability testing, showing the summing circuit performance (both in time and amplitude). It consists on the concatenation of two consequent tone bursts of 1 kHz for a T time span, that are later subdivided. ANSI S1.25 further explains it on item 7.7.

Doubtless the main test of ANSI is "Squaring, Averaging, and Exponential Circuit", which cannot be verified using IEC 61672 signals, neither using signals from the obsolete IEC 60651. Equation 2 makes clear that in this standard integration is based on time weighted sound levels. Those tests are similar, if not identical, to those defined on IEC 60804 pulse range test. It consists on a continuous 4 kHz tone burst that is repeated at four defined time span steps, as further explained on ANSI S1.25 (item 7.5), with its tolerances defined for each time weighting and each time step. The time spans of high-level signals are such that interact with time constants, as seen on Table 3:

Table 3 – Excerpt from ANSI S1.25 indicating expected values and tolerances for "Squaring, Averaging, and Exponential Circuit " test

TABLE 4-A. 53 dB Pulse range (SLOW time constant) averaging				
Burst duration	Exchange rate			Tolerance
	3	4	5	
1ms	10.4 dB	9.2 dB	8.4 dB	±2.5 dB
10ms	20.0 dB	18.5 dB	17.3 dB	±2.5 dB
100ms	30.0 dB	28.4 dB	27.1 dB	±2.5 dB
1s	40.0 dB	38.6 dB	37.5 dB	±2.5 dB
TABLE 4-B. 53 dB Pulse range (FAST time constant) averaging				
Burst duration	Exchange rate			Tolerance
	3	4	5	
1ms	10.4 dB	7.2 dB	5.3 dB	±2.5 dB
10ms	20.0 dB	15.8 dB	12.4 dB	±2.5 dB
100ms	30.0 dB	25.7 dB	21.8 dB	±2.5 dB
1s	40.0 dB	37.1 dB	34.3 dB	±2.5 dB

A revision of IEC 61252 should contemplate tone bursts with characteristics that interact to time constants as those. Considering the case of using the same tone bursts of current IEC 61252, it would only need to define expected dose values and tolerances.

3. CONFORMITY RESULTS IN CALIBRATIONS AND ANALYSIS

A list containing the sound exposure meter models that were included on this work is shown on Table 4, in alphabetical order. Each of those manufacturers declares conformity to IEC 61252 and ANSI S1.25 for every model shown in that list.

Table 4 – List of tested noise dosimeter models (in alphabetical order)

Manufacturer	Model	Origin	Manufacturer	Model	Origin
01dB	Wed 007	France	Incon	IDAC 100	Brazil
3M	Edge eg5	USA	Instrutherm	DOS 600	China
Casella Cel	350	UK	Larson Davis	Spark 706	USA
Chrompack	SmartdB	Brazil	Quest	NoisePro	USA
Criffer	Sonus 2	Brazil	Quest	Q300	USA
Extech	SL355	China	Svantek	SV104	Poland

For confidentiality sake, each model was randomly codified, from A1 to A12.

3.1 Pressure Field Acoustic Test Comparison

It is remarkable that, while IEC 61672-3 indicates an acoustical test in 3 frequencies - 125 Hz, 1 kHz and 8 kHz - IEC 61252 revision proposes a single sensitivity adjust test in 1 kHz. The importance and need for frequency range expanding for assuring measuring reliability was shown by the authors elsewhere [10]. Considering extreme environmental conditions to which noise dosimeter microphones are subjected, frequency response control is paramount.

Table 5 shows pressure-field acoustical test responses for every tested model by means of a Brüel & Kjær type 4226 multi-frequency sound level calibrator. It is noticeable that applying corrections for free-field or random incidence, as respectively indicated by IEC 61252 and ANSI S1.25, would make it even harder for any project to acoustically meet both standard's tolerances, especially at higher frequencies.

Models A5 and A10 are interesting cases, once results in pressure-field showed high gains that exceed tolerance. Considering that a correction for free-field and random incidence will always be positive values, even for a small correction those models' final errors would be even greater. In other words, acoustical test for those models would exceed tolerances on every sound field. There are also cases of errors in pressure-field that are too close to tolerances, so much so that applying a correction data could change conclusions regarding their conformity.

Table 5 – Errors in dB for pressure-field acoustical tests normalized at 1 kHz

Frequency	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Tol ±	2,0	1,5	1,5	1,5	---	2,0	3,0	5,0
A1	0,6	0,4	0,1	0,1	0	0,1	-0,7	-0,9
A2	0,1	0,0	0,0	0,0	0	-0,3	-0,7	-2,7
A3	0,5	0,3	0,2	0,2	0	-0,4	0,7	-4,9
A4	0,1	0,3	0,3	0,2	0	-0,2	0,0	-0,3
A5	0,3	0,0	-0,1	-0,1	0	0,3	2,5	12,6
A6	0,9	0,9	0,8	0,6	0	-1,2	-2,9	-0,5
A7	-0,6	-0,1	0,0	0,1	0	-0,1	-0,5	-4,1
A8	-0,3	0,0	0,0	0,0	0	0,1	0,4	-3,3
A9	-0,2	-0,2	-0,2	-0,1	0	-0,1	-0,5	0,9
A10	-0,2	-0,6	-1,8	-0,1	0	0,8	6,3	-3,7
A11	0,2	-0,1	-0,1	-0,1	0	0,1	0,6	4,0
A12	0,3	0,3	0,2	0,2	0	-0,4	-1,4	-0,3

Model A5 shows a stable acoustical response up to 2 kHz, while its error at 8 kHz presents variations between 4 dB and 20 dB. Such a variation on different samples of the same model show a deficiency on transducers' quality. On the other hand, model A4 presents a virtually flat response, proving that a low-cost noise dosimeter microphone project is perfectly feasible. This fact was already shown by the authors elsewhere [4].

Of 12 tested models, only one of them has a standardized IEC 61094-4 ¼” capacitive microphone. The rest of them are low cost electret microphones. However, acoustical tests allow to prove that there are low cost microphone models that have good performance and proper frequency response for its final purpose.

Model A10 showed a peculiar acoustic performance, having a considerable error at 4 kHz, confirmed by more than 5 samples of this same model. IEC 61252 electrical tests were satisfactory, but the model has huge errors considering ANSI S1.25, proving the difficulty of making a good project for integrating dose.

Moreover, models A3, A6, A7 and A11 show results close to tolerance limits for some frequencies, even though it is still necessary to further discuss the proper sound field to which microphones should be designed and tested, as mentioned before. Reported values on this study are in pressure field, and, if corrections are applied, some results could change from conform to non-conform and vice-versa. It is good to remember that noise dosimeters are designed for using on working environments, and are usually exposed to extreme temperature, humidity, vibration and dust conditions. Microphones could suffer, and it is known to be the case, changing their sensitivity and frequency response because of those conditions. Just periodic tests that cover the whole frequency range are capable of detecting those kinds of shifting.

3.2 Performance comparison by both standards on relevant tests

Table 6 allows to compare integration performance for every model considering the relevant electrical tests by IEC 61252 and ANSI S1.25. Those are tests that most stress standards' differences concerning integration calculation and constructive blocks.

Table 6 – Relevant tests results by IEC 61252 and ANSI S1.25 (codified list)

Code	IEC 61252 Short-duration signals	IEC 61252 Unipolar pulses	ANSI S1.25 Squaring, Averaging, and Exponential Circuit	ANSI S1.25 Exponent Circuit and Integrator
A1	ok	ok	---	---
A2	ok	ok	ok	ok
A3	---	---	exceeds tolerance	ok
A4	ok	ok	ok	ok
A5	---	---	ok	ok
A6	ok	ok	ok	ok
A7	exceeds tolerance	ok	exceeds tolerance	ok
A8	ok	ok	exceeds tolerance	ok
A9	ok	ok	ok	ok
A10	ok	ok	exceeds tolerance	ok
A11	ok	ok	ok	ok
A12	ok	ok	ok	ok

"---" no data available

Some considerations can be made in view of Table 6. Models A2, A4, A6, A9, A11 and A12 show that it is possible for a given noise dosimeter project to successfully meet integration requirements by both standards. Models A3, A7, A8 and A10 show that dose calculation requirements by ANSI S1.25 offer greater difficulties to the project. Models A8 and A10 show that a given noise dosimeter can meet integration requirements by IEC 61252 and fail to accomplish it by ANSI S1.25. In fact, A7 was the only tested model that does not even meets IEC 61252 tolerances. On the contrary, considering a total of 11 models tested by ANSI S1.25, there are 4 of them that failed to meet integration tolerances to short-duration signals. All of the 11 models tested were able to properly integrate long-duration tone bursts.

3.2 Worst case for electrical errors by ANSI S1.25

Table 7 brings the worst-case errors for Squaring, Averaging, and Exponential Circuit among the models on this work. When considering how expressive the errors reported for A10 are on ANSI S1.25 tests, someone could even question if those tests were properly executed. However, it needs to be considered that model A10 was subjected to the very same tone bursts that models A2, A5, A6, A9 and A12. In those last cases, results had successfully met standard tolerances for every and each one. It is good to remember that A10 also met IEC 61252 tolerances.

Table 7 – Errors in dB for "Squaring, Averaging, and Exponential Circuit" test by ANSI S1.25, ± 2,5 dB tolerance - based on 5 samples of A10 model, S1 to S5 (left), and randomly chosen samples from models A2, A5, A6, A9 and A12 (right).

	Worst-case (A10)					Good cases				
	S1	S2	S3	S4	S5	A2	A5	A6	A9	A12
Burst	SLOW					SLOW				
1ms	1,1	-0,2	0,6	0,8	0,4	0,1	-1,4	0,4	0,3	-0,2
10ms	0,6	0,1	0,7	0,7	0,4	0,1	-2,3	0,9	0,8	-0,3
100ms	0,6	5,6	5,3	5,2	5,8	0,1	0,0	1,1	1,2	-0,3
1s	4,3	8,8	10,0	9,9	9,7	-0,1	0,1	1,3	1,2	-0,2
Burst	FAST					FAST				
1ms	1,2	10,1	3,3	3,7	3,7	-0,2	-1,5	-0,1	-0,2	-0,4
10ms	6,1	18,5	17,9	18,2	18,7	0,0	1,1	0,1	0,1	-0,8
100ms	17,8	17,1	25,1	25,0	24,8	0,0	-0,6	0,2	0,5	-0,8
1s	12,8	14,8	15,6	15,6	15,3	-0,1	-0,3	0,8	0,7	-0,4

Many manufacturers declare noise dosimeter conformity to sound level meter standards as IEC 61672 and IEC 60651. Even though IEC 60651 is already an obsolete standard, it is still referred by some manufacturers, perhaps because of its former worldwide acceptance, benefiting users that are familiarized to it. It is good to mention that the manufacturer from model A10 declares conformity to IEC 61252, ANSI S1.25, IEC 60651 and IEC 61672, besides filter standards.

The calibration laboratory also tested model A10 using IEC 60651 signals, and it was conforming to its tolerances for every electrical test of it, including time weighting tests with considerably low errors. Comparing results that are so incompatible, as the ones obtained by IEC 60651 and ANSI S.125, it is clear that noise dosimeter conformity as sound level meter does not mean conformity as a noise dosimeter itself. That is to say that, if a calibration laboratory seeks to assure that an item is adequate for using as noise dosimeter, considering time weightings and doubling factors other than Q = 3, it could not guarantee that by means of tests specified in standards other than ANSI S1.25. In this regard, it is important that the revision of IEC 61252 should include tone burst and amplification/attenuation values, as expected for each test and specifically calculated conforming equations 1 and 2.

4. CONCLUSIONS

First, it is clear from a simple specification inspection that the two current noise dosimeter standards are significantly different. Even though tests as linearity and frequency response are similar, they are not representative of the whole, once those tests are present in almost every acoustic equipment standard. Considering that their difference hinges on logic and constructive blocks, that is to say, in considering or not time weightings and different exchange rates, the tests that show their difference are exactly those that stress integration capability.

Therefore, if a given noise dosimeter has an adequate performance when tested by one of those standards, it does not follow that it also has an adequate performance by the other. In other words, correctly calculating Pa^2h by IEC 61252 does not mean a correct %Dose calculation by ANSI S1.25. Additionally, an adequate performance by any other acoustic equipment standard, as IEC 61672, and the obsoletes IEC 60651, says nothing about an equipment's performance as a noise dosimeter.

This reality has significant importance, especially in contexts where work legislation uses exchange rate values other than 3. For instance, in Brazil, where work legislation refers to Q=5. If a given noise dosimeter is tested and found conforming to IEC 61252, it does not mean that it is adequate for using in legal noise dosimetry, even though there are some legal peculiarities that are not relevant at this point. This is also true for a noise dosimeter tested by any other sound level meter standard, or even filter standards, as unfortunately is a common practice by some laboratories.

Moreover, calibration results give grounds to affirm that adequate determination of acoustical energy calculated through squared sound pressure integration, as specified by IEC 61252, is not a "challenge" for manufacturers. In that sense, approximating its revision's requirements to IEC 61672 makes sense, and all developments contained in this standard series could be perfectly adopted to it. There are L_{AE} tests on IEC 61672-3 that could be perfectly adapted for sound exposure meters on IEC 61252 revision.

On the other hand, if the revision proposed for IEC 61252 seeks to reach countries whose work legislation currently point to ANSI S1.25, as Brazil or the USA, it would also be necessary to calculate expected %Dose or L_{AVG} for new short-duration tone bursts. Those tone bursts should be able to interact with time weighting constants (F and S), assuring that a given manufacturer's project could properly calculate noise dose by Equation 2. A simpler solution would be to propose a hybrid standard, considering results for short-duration tone bursts for Q=3, as it had already appeared on IEC 61252 revision proposal, but also tests with short-duration tone bursts and $Q \neq 3$, as ANSI S1.25 presents on item 7.5, tables 4A and 4B.

Finally, regarding noise dosimeter microphones, it is important that IEC 61252 revision should carefully consider which sound field is appropriate for this kind of application. In this regard, ANSI S1.25 seems more adequate when pointing to a random incidence microphone. However, testing a microphone's whole frequency range, especially higher frequencies, is paramount to noise dosimetry reliability. Failing to do so could jeopardize all of the advancements in electrical testing.

5. ACKNOWLEDGEMENTS

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