Noise dosimeter microphones: an evaluation of the measurement reliability

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ABSTRACT

One of the most practically useful equipment on acoustics is the sound exposure meter, commonly known as noise dosimeter, widely spread on the industry to estimate potential hearing loss of the workers. Despite its importance, the noise dosimeter is much underestimated, having generally lower quality components when compared to other equipment of acoustics metrology field, i.e. sound level meters, modular measuring systems, etc. This fact is remarkable when looking at microphones, main item of any acoustics measuring chain. The microphones used in almost all the noise dosimeters are not standardized despite the common sense that to assure measurement reliability, microphones should meet international manufacturing and testing standards. The present noise-dosimeter standards are not conclusive about the right acoustic field to which microphones for this task should be constructed. For those reasons, the frequency response on free-field, diffuse-field and pressure-field of a population of noise dosimeter's microphones of a worldly well-known brand will be determined and compared to present applicable international standards to evaluate the actual reliability of the measures produced by this kind of equipment.

Keywords: Noise dosimeter, Microphone, Sound exposure meter
I-INCE Classification of Subjects Number(s): 71.4; 71.9; 78

1. INTRODUCTION

When it comes to acoustic measurements, surely one of the first equipment to be mentioned by an industry expert is the sound exposure meter, known too as noise dosimeter. It is used mainly by the health and safety sectors, helping to estimate potential hearing loss of the workers. A noise dosimeter basically measures the sound pressure to which the worker is exposed. This measurement is made by a transducer, in this case a microphone, and, after the conversion from sound pressure to electric signal, through integrating, weighting and squaring circuits, the equipment provides a sound exposure, sound pressure or dose value (1). This value is to be used for the evaluation of the worker's potential hearing loss.

One of the most important items in any acoustic measure chain is the microphone, if not the most important in fact. It should be expected that for a so widely spread equipment as the noise dosimeter is, high quality microphones would be used, once the direct impact of the final measure is so important: the hearing integrity of the workers. However, this is not the current market practice; the microphones provided with almost all noise dosimeters are not standardized despite the common sense of specialists that for measure reliability, microphones should necessarily meet construction and testing standards (2).

In the other hand, microphones that are actually manufactured meeting international standards, besides having a high cost, are in general very delicate; any touch on the membrane, falling off or even dirt accumulation could permanently damage it. The need of using this kind of microphones in hostile environments like factory floor could be considered unnecessarily accurate by some people, or even a market reserve of the traditional microphone manufacturers against the raising of the OEM equipment and transducers.

There are international standards that specify manufacturing parameters and tolerances for the noise dosimeter's electrical signal processing (3, 4). Since dosimetry measurements do not require much restrictive tolerances when compared to other areas on the acoustic metrology field, a possible measuring instability or non-linearity of the frequency response could be another component to the uncertainty estimation. Moreover, other error sources are probably much more representative than the ones related to the microphone, i.e. microphone positioning on the worker. Furthermore, the results of dosimetry are used as criteria for the need of audiometric testing on the worker, that have even broader tolerances as described on international standards (5).

The environment on which the noise dosimeter is used is usually factory floor or other places close to stationary sound sources, with high sound pressure levels coming from many directions in general, this is better approximate by a diffuse field. It is very important for health and safety sectors to have an evaluation of the actual reliability of noise dosimeter’s measures. For this, first it is necessary to have a population of similar microphones to obtain each individual performance, frequency response and dispersion in the sound field that better represents the actual measuring condition and compare them to the applicable international standard’s tolerances.

2. MICROPHONES TESTING

2.1 Selecting the sample

Determining the reliability of the whole noise dosimeter would require a testing that would look like a pattern evaluation for every brand and model, and also for all the microphones that are compatible with them. This would be almost impossible because of the great cost and time required for this task. By the time of planning the tests, many manufacturers’ offices and retailers were contacted to lend some samples of microphones in order to have as many brands as possible represented, but only one brand provided a considerable number of microphones for the tests. Therefore a population of new noise dosimeter microphones of that same brand and model was tested as a representative of this kind of instrument, and the results of testing could be a motivation for further studies for other brands and model of both noise-dosimeters and microphones.

The considerable sample number added valuable information, dispersion between new microphones of the same model in relation to the mean group response. Moreover, it is necessary to have many microphones to give robustness to the estimation of a typical response for that model, and typical field corrections as well.

After selecting the population, the microphones were tested to all the sound fields in order to produce a broader conclusion about their performance, and also for the lacking of conclusion in the standards about the sound field that best represents the actual measuring condition. The tests for free-field and diffuse-field were performed starting at 1 kHz and the tests for pressure-field were performed starting at 63 Hz. The frequency response was normalized at 1 kHz as usual for noise dosimeters. Once there are expected almost the same results for frequencies below 1 kHz for all of those three acoustic fields and also for practical testing issues, the pressure-field response was assumed as the actual response for all of them on those frequencies.

2.2 Free-field testing

The guideline for free-field testing was the IEC 61094-8 (6). The equipment used for this testing were: laboratory standard microphone as reference, pre-amplifier, data acquisition module, software for signal manipulation, speaker and function generator.

An adaptation was made on the original noise dosimeter’s base in order to allow the electrical signal to be acquired directly from the microphone at the same time that the original circuit was providing the original power source for the microphone to work. This adaptation was also used for testing in diffuse-field and pressure-field.

The function generator excited the speaker with an optimized function that considered the speaker’s frequency response and the goal frequency range for the test. Both reference and testing microphones were placed at the exact same spot in order to guarantee that they are far enough from any potential reflection surfaces and to subject them to same condition as well. The signals from the testing microphones attached to the noise dosimeter’s base and from the reference microphone attached to the pre-amplifier were sent to the data acquisition module and further processed using a time-selective technique with signal manipulation software.

This procedure was repeated three times at least for each microphone of the population to prevent errors on the measuring process. The results of the free-field testing are shown on the Figure 1:

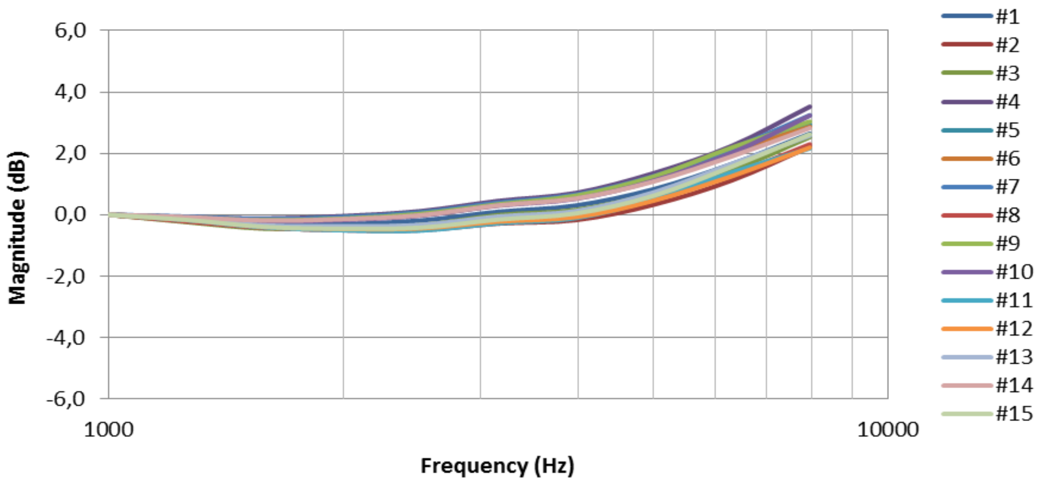

Figure 1 – Free-field frequency response of the 15 noise dosimeter microphones

2.3 Diffuse-field testing

The guideline for diffuse-field testing was the IEC 61183 (7). Similarly to the first test, the equipment used for this testing included a laboratory standard microphone as reference and a pre-amplifier, but also a frequency analyzer, two reference sound sources and a rotational boom.

The reference sound sources were placed on each opposite corner of a reverberating chamber to optimize the directionally random sound wave reflections. The microphones under test as well as the reference microphone were placed in the exact same spot attached to the rotational boom to assure that both were submitted to the same spatial conditions. The frequency analyzer recorded and integrated the signal given both by the reference and testing microphones while the boom was making a spatial average inside the reverberating chamber excited by the sound sources. The integration time was defined according to the goal frequency range.

This procedure was repeated three times at least for each microphone of the population as well to prevent measurement errors. The results of the diffuse-field testing are shown on the Figure 2:

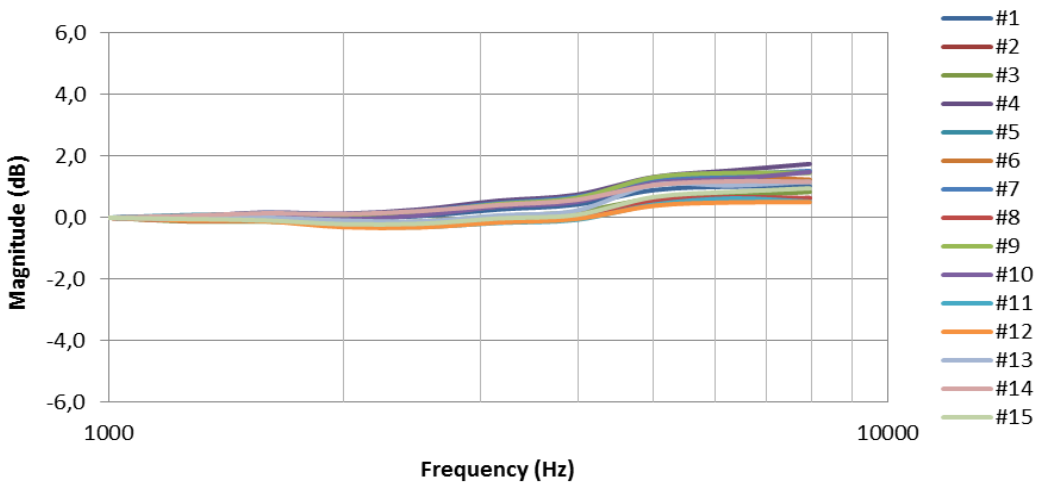

Figure 2 – Diffuse-field frequency response of the 15 noise dosimeter microphones

2.4 Pressure-field testing

The guideline for pressure-field testing was the IEC 61094-5 (9). The equipment used for this testing included a laboratory standard microphone as reference, pre-amplifier, comparison coupler, function generator, a measuring amplifier and two voltmeter channels on the acquisition system.

One problem faced for pressure-field calibration was the dimension of the microphone. The comparison coupler have 1,27 cm (½”) cavities, it is absolutely compatible with the reference microphone, but for the noise dosimeter microphones an adaptation was needed to successfully attach it to the coupler.

After solving this problem by making an adaptation to the capsules, both microphones were positioned face to face inside the comparison coupler. That coupler was excited by the function generator and the signals were simultaneously read by the voltmeters, the test signal directly from the noise dosimeter's base and the signal of the reference microphone after passing through the pre-amplifier and measuring amplifier.

Once again, this procedure was repeated three times at least for each microphone of the population to prevent errors. Figure 3 shows the results of pressure-field testing:

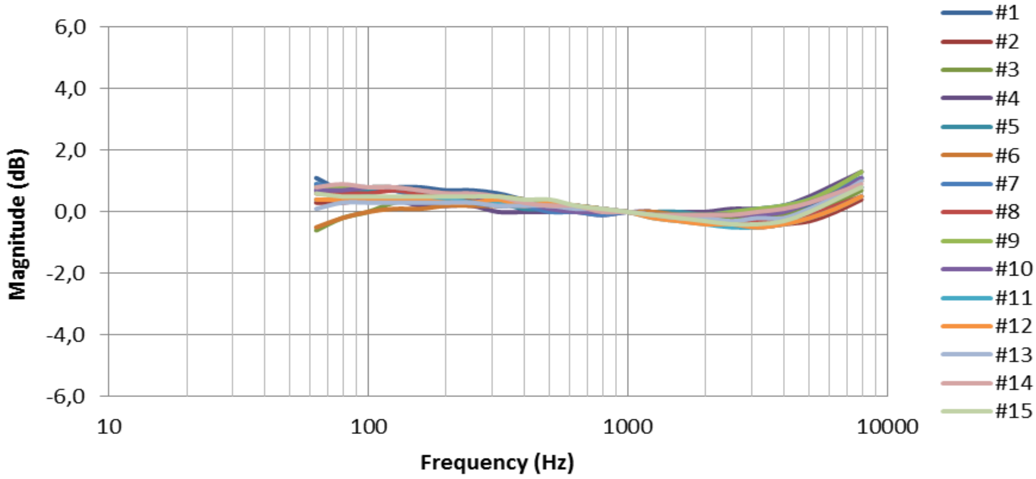

Figure 3 – Pressure-field frequency response of the 15 noise dosimeter microphones

2.5 Electrical testing

Besides the microphone response it is necessary to determine the electrical response of the equipment's base to have an accurate total error that the final users actually have on their measurements.

The electrical frequency response test is actually present in almost every standard for sound measuring equipment. The test basically consist in applying an electrical steady, single frequency, sinusoidal signal in the same place that the original microphone inserts its signal. The frequency of the signal is varied according to the frequency range established on the standard.

A signal generator was used as reference for this test. The reference frequency range used is present on the IEC 61252 (3) and the test was performed according to the guidelines of this standard, adjusting the reference test value in 1 kHz and varying frequency in octave steps from 63 Hz up to 8 kHz. Table 1 shows the final mean result for this testing:

Table 1 – Electrical frequency response of the noise dosimeter's base

Frequency, Hz	Error, dB
63	-0,2
125	-0,1
250	-0,1
500	-0,1
1000	0,0
2000	0,0
4000	0,1
8000	-1,8

3. RESULTS AND TOLERANCES

3.1 Typical response of the microphone

It is clear by the previous results that the microphone was constructed to have a flat pressure field response, and it would be sufficient to test it periodically to that field. Having those three frequency responses in different sound fields it is possible to propose a typical response, and consequently approximated correction factors for one field to another. Table 2 shows the typical microphone's response normalized at 1 kHz, that is usually the adjust frequency of the sound level calibrator used by noise-dosimeters' users:

Table 2 – Typical frequency response of this microphone model

Frequency, Hz	Pressure-field, dB	Diffuse-field, dB	Free-field, dB
63	0,5	0,5	0,5
80	0,5	0,5	0,5
100	0,5	0,5	0,5
125	0,5	0,5	0,5
160	0,5	0,5	0,5
200	0,4	0,4	0,4
250	0,4	0,4	0,4
315	0,4	0,4	0,4
400	0,3	0,3	0,3
500	0,2	0,2	0,2
630	0,1	0,1	0,1
800	0,1	0,1	0,1
1000	0,0	0,0	0,0
1250	-0,1	0,0	-0,1
1600	-0,2	0,0	-0,3
2000	-0,2	-0,1	-0,3
2500	-0,2	0,0	-0,2
3150	-0,2	0,2	0,1
4000	-0,1	0,3	0,3
5000	0,1	0,9	0,9
6300	0,5	1,0	1,7
8000	0,9	1,1	2,7

This information is very important. Almost every manufacturer of microphones that are made in accordance to international standards guidelines provides this data with their product. When it comes to requirements of other related standards, i.e. sound level meter standards, only microphones that provide applicable correction factors can be used with equipment that meets the IEC 61672-1 (8).

3.2 Typical response of the noise dosimeter

Once the typical microphone's response is available, a simple sum of this data to the electrical response provides us the typical response of the noise dosimeter. For determining this response, the diffuse-field data was used, despite some discussions about the microphone's "proper" sound field that will be developed ahead. Table 3 shows noise dosimeter's typical response:

Table 3 – Typical response of the noise dosimeter with this microphone's model

Frequency, Hz	Error, dB
63	0,3
125	0,4
250	0,3
500	0,1
1000	0,0
2000	0,0
4000	0,5
8000	-0,7

As the name says, it is a typical response and it may vary from sample to sample. Figure 4 shows the maximum error found from sample to sample in relation to the typical response considering the microphone's diffuse field response. Electrical response differences were irrelevant for the whole population. It should be considered that usually the uncertainty related to higher frequencies is considerably greater than the related to medium and lower frequencies.

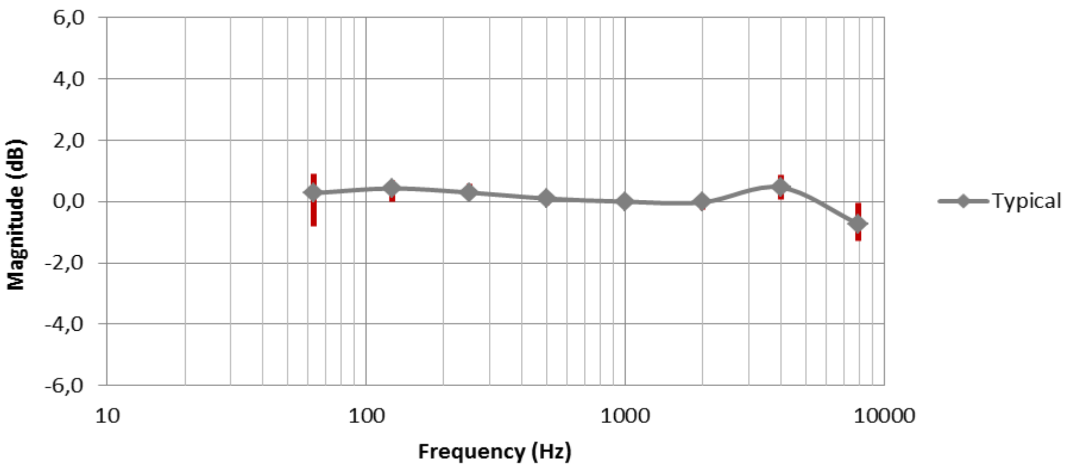

Figure 4 – Typical response of the noise dosimeter with maximum errors

3.3 Standards and tolerances

To evaluate if measurements that are made with the current available noise dosimeters are actually reliable, there is a need to compare the typical response of this noise dosimeter to tolerances for frequency response used on applicable international standards.

The first tolerance to which these results should be compared is the one reported on current noise dosimeter's standards (3, 4) and both are the same for the frequency response test. Another tolerance that is relevant for this analysis is present on audiometer's standard (5), once the end of the measuring chain that is used for quantify worker's hearing loss is actually the audiometric testing.

Finally to position this typical response in comparison to hand-held acoustic equipment that are considered reliable, the tolerance of the current sound level meter standard (8) will also be used as a parameter. The tolerance for a class 2 sound level meter would closer to the performance expected for a noise-dosimeter, but the class 1 tolerance was chosen to be even stricter in this analysis.

Figure 5 shows the typical response compared to those 3 standards. The results on this are based on the microphone's diffuse field response, for the pressure field response the results would be even closer to a flat response. On the figure, NDM, SLM and ADM stands for, respectively, the noise dosimeter, sound level meter and audiometer standard's tolerances. The signals "+" and "–" represent the upper and lower parts of the tolerances.

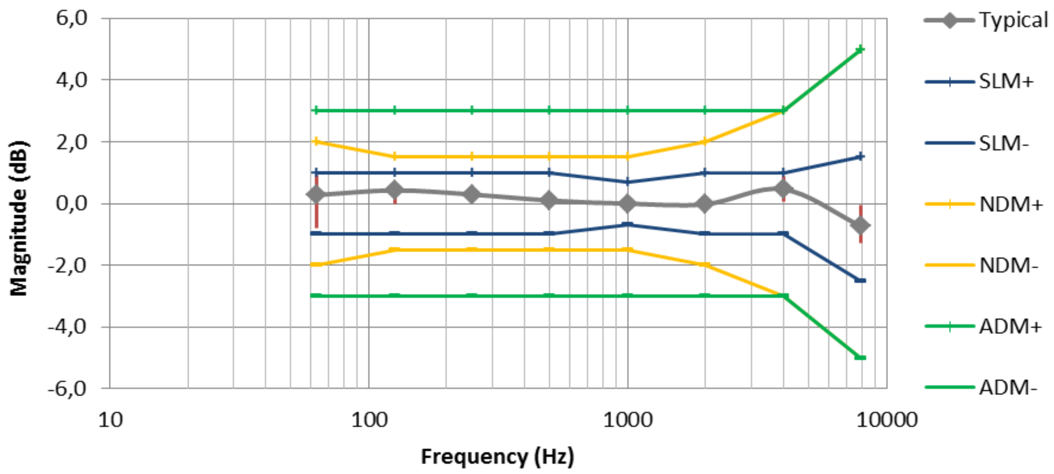

Figure 5 –Tolerances and typical response with maximum errors

4. CURRENT PLOBLEMS

4.1 “Proper” sound field

One of the current problems relating to noise dosimeters is to which sound field the microphone should be constructed, that is, which sound field better represents the actual measuring condition. Even the current standards are not in accord to each other on this point. The ANSI S1.25 on 7.2.2 refers to testing the microphone in a diffuse sound field (4). In the other hand the IEC 61252 on the note of 6.2 refers to the need of a correction factor to free-field when calibrating microphones by means of a closed-coupler (3).

A test was performed to estimate the “free-field” response with a microphone attached to a person. Obviously due to the person there this is not “free-field” anymore, but test shows actual measuring condition of the final user on a “free-field” condition. The test was performed similarly to the free-field calibration, but attached to the chest, close to the ear and to the shoulder of the same person. The results are shown in Figure 6:

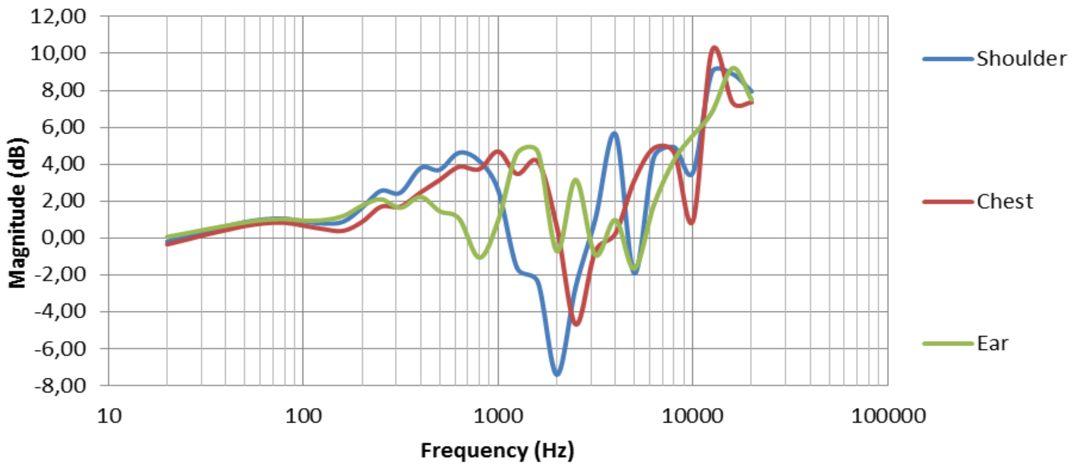

Figure 6 – “Free-field” response of the microphone attached to a person

This image clearly shows that the influence of the microphone’s positioning is huge on frequency response, reaching up to 7 dB on frequencies between 63 Hz and 8 kHz, for that reason, the correct positioning of the microphone is essential to a good dosimetry. It also reveals that a free-field testing of the noise dosimeter has no relation to the actual final measure, and thus almost no practical value for evaluating the microphone’s reliability.

Diffuse-field at first seems to be the best approach for the common usage of noise dosimeters: an industry with many sound sources and many reflection surfaces. The problem related to this is that the person itself is a wave absorber, and thus the sound field is not perfectly diffuse anymore. Another problem is that not always a person is on a place with many sound sources, the worker could be at an office near a production line, or at a production line with only one high sound level source, etc.

In addition to these two points of view, someone could defend that the best approach to the correct field for a microphone attached to a person's body is pressure-field. The sound wave would practically have no reflection because of the person's body and for that reason the microphone would be in a situation that is better approached by a pressure-field.

4.2 Testing interval

Interval for testing is always a great discussion among metrologists, especially when it comes to users in large industries where is common to try to cut costs anyway. Normally, noise dosimeters would require a one-year length of time between calibrations as a good practice recommendation, but some test with used noise dosimeters showed that depending on the harshness to which the microphones are exposed to, the periodicity could be even shorter. A pressure-field testing was proceeded with some used microphones of the same brand and model of the previously mentioned. The microphones used for this test have between 1 and 3 years of use and are from three different users that include industries and measuring consultants. Figure 7 shows this pressure-field response:

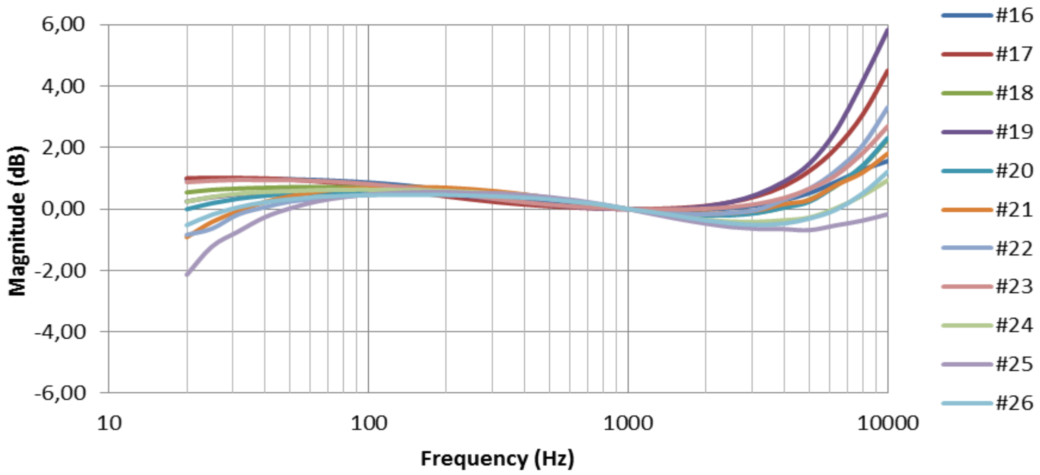

Figure 7 – Pressure-field response of old noise dosimeter microphones

It is remarkable the great difference compared to new microphones, mainly on lower and higher frequencies. The dispersion of the individual responses shows that the drifting of responses is very particular to the harshness and duty cycle of each sample. This means that trusting on model's typical response is at least risky, and undoubtedly enlarging the calibration interval could be critical.

It should be considered also that those results were obtained in environment controlled laboratories, and the effects of temperature, humidity, and others surely have impact on the measurements. For this reason also, the periodic testing for this kind of microphone is essential and should not be left aside by the standards. Therefore just by historical test performance and right estimation of the testing interval the measuring reliability could be assured for the final user.

4.3 Standard testing methodology

Testing methodology in standards basically could be divided in two parts: pattern approval and periodic test. The first one is more directed for manufacturers and primary laboratories, and the final client just has access to the final result: approved. The periodic test is where the need for microphone testing is more sensible, for in this case the client will have access to actual data that allows conclusions on the reliability of routine measurements. The problem relies on the undefined sound field matter, but the needs and feasibility of each sound field calibration can be discussed.

First, supposing that noise dosimeter's microphone is a free-field microphone leads to the problem demonstrated before. The free-field calibration has no relation to the actual response of the microphone when attached to a person. Furthermore, for this to be a periodic test it would be necessary to have facilities that generally secondary laboratories don't have, as an anechoic room, time-selective technique apparatus, etc. In addition to that, in general, noise dosimeters do not have an AC voltage output that allows data to be acquired for calibration with time-selective techniques without making technical interventions on the equipment.

Second, supposing that the noise dosimeter's microphone is a diffuse-field microphone leads again to the cost problem. Calibration in an actual diffuse field would be very expensive, for it is necessary a reverberating chamber, or means to do a free-field calibration with many incidence angles, which is more complex and takes more time. Once again, the lacking of voltage output in noise dosimeters makes this calibration practically impossible without interventions on the equipment.

The only option is to test in pressure-field. This possibility is actually mentioned on the note of 6.2 on the IEC 61252 (3), and the standard is right to say that a correction factor will be needed, both if the microphones is a free-field or diffuse-field. If the pressure-field microphone thesis is the most accurate for noise dosimeters, this problem is altogether solved, for the calibration is already on the right field, although this thesis is not cited by any standard. The problem here is that normally the noise dosimeter's microphone dimensions varies from model to model, and the calibration coupler generally have 1,27 cm (½") cavity, for this reason, it would be necessary in the future that manufacturers provide adaptors with the microphone for this requirement.

5. CONCLUSIONS

It is clear by the results that when the final goal of noise dosimeter's microphones is put to test, its performance is very good comparing to current tolerances of applicable standards, even with some old samples of those microphones.

Despite this good performance, microphones that are not standardized cannot be compared to the know measurement microphones that meet standard's requirements. The stability and consistency on frequency response found on the specifications and calibration history of the traditional standardized measuring microphones are much more restrictive.

Moreover, the difficulties in testing according to current microphone standards and the lacking of regulation on noise dosimeter standards should be a discussion point for future revisions of the ISO and ANSI standards, for the periodic test proved to be feasible and the only way to assure reliability for this equipment. It is good to reinforce the need for an AC voltage output and 1,27 cm (½") adaptors provided by the manufacturers for proper testing.

It can also be concluded that it would be a good guideline, or even normative requirement, to use pressure field flat response microphones for noise-dosimeters. This would allow feasible periodic testing and besides it, the results could be easily converted to diffuse field response with considerably low corrections. It would also stop the confusion with free-field responses and correction factors that proved to be useless for this kind of measurement.

Obviously those tests refers to just one brand and model, but this good performance shows that it is possible and should be mandatory to make low cost tough microphones that in fact meet standards tolerances, for this is the best option for hostile environment as industry floor. In this aimed reality and with periodic standardized tests the final client will be able to rest assure that their dosimetry measures are well based on firm test requirements just as any other acoustical measure.

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REFERENCES

1. Kardous CA. Noise Dosimeter In: Crocker MJ, editor. Handbook of Noise and Vibration Control. 1st ed. New Jersey, USA: Wiley; 2007. p. 465-469.
2. ISO/IEC 61094-4:1995: Specification for working standard microphones.
3. ISO/IEC 61252:2002: Specifications for sound exposure meters.
4. ANSI S1.25:1991 - Specification for Personal Noise Dosimeters.
5. ISO/IEC 60645-1:2012: Equipment for pure-tone audiometry.
6. ISO/IEC 61094-8:2012: Methods for determining the free-field sensitivity of working standard microphones by comparison.
7. ISO/IEC 61183:1994: Random-incidence and diffuse-field calibration of sound level meters.
8. ISO/IEC 61672-1:2013: Sound level meters - Part 1: Specifications.
9. ISO/IEC 61094-5:2001: Methods for pressure calibration of working standard microphones by comparison.