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Personal sound exposure meters: A study of measurements methods of the acoustic performance for pattern evaluation

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Abstract

This paper shows a study of measurement methods for evaluating the acoustic performance of personal sound exposure meters focusing on pattern evaluation. The methods developed in this investigation follow the principles established in methods of sequential comparison in diffuse-field (using a reverberation chamber) and in free-field (using an anechoic chamber). A torso simulator is used in this study to simulate the real case of a worker using a personal sound exposure meter. In addition, part of this study is a particular case that does not use the torso simulator, but follows what is recommended in the calibration of sound level meters in free-field.

Keywords: personal sound exposure meter, diffuse-field, free-field, torso simulator.

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1. INTRODUCTION

The objective of this investigation is to estimate how the choice of the measurement method impact on the evaluation of acoustic performance of personal sound exposure meters with focus on pattern evaluation.

Revision of IEC 61252:1993 [1] is ongoing in the Technical Committee no. 29 of International Electrotechnical Commission (IEC). At meetings held on October 2021 and on December 2021, some requirements for pattern evaluation and periodic tests of personal sound exposure meters were discussed.

Regarding the acoustic performance assessment requirement of personal sound exposure meters for pattern evaluation, there was a long discussion about: 1) if it should be performed in free or diffuse sound field; and 2) if it should be used a torso simulator or not. Brazil position was that the diffuse-field comparison method according to IEC 61183 [2] is the most appropriate one. If the option is also to carry out measurements in free sound

field, then the Brazilian proposal was to use a torso simulator. In this case, the reference microphone and, sequentially, the microphone of the personal sound exposure meter under test should be mounted in the position of use indicated by ISO 9612 [3] (over the shoulder of the torso and 10 cm away from the entrance to the ear canal). The Brazilian proposal was understood, but more information and data were requested.

2. PROPOSAL

This investigation is shared in two steps: one performed in diffuse sound field and another, in free sound field.

In diffuse sound field, in the first measurement configuration, the microphone of the device under test will be mounted on the shoulder of a torso simulator according to ISO 9612 [3], i.e. the diaphragm of microphone is 10 cm away from the entrance of the ear canal. As the diffuse-field sequential comparison method is used, the reference microphone will be mounted at the same point the microphone of device under test is mounted. In the second



measurement configuration, the reference microphone/device under test will be mounted on a rotating boom following the diffuse-field sequential comparison method described in IEC 61183 [2].

In free sound field, acoustic performance measurements using the sequential comparison method will be performed, but in three different measurement configurations. In the first configuration, both the reference microphone and the microphone of the device under test will be mounted on the shoulder of a torso simulator in accordance with ISO 9612 [3]. In the second configuration, both the reference microphone and the device under test will be mounted on a positioning rod, as described in the EURAMET.AUV.A-S2 comparison report [4]. In the last configuration, the reference microphone will be mounted on the positioning rod and the microphone of the device under test will be mounted on a torso simulator in accordance with ISO 9612 [3].

3. SETUP AND FACILITIES

In the construction of a personal sound exposure meters, it is not defined which microphones types (free-field or pressure field response) are used. This definition is very important because, depending on the type of microphone used, it will reflect on their frequency response. Personal sound exposure meters that have a free-field microphone will only have a flat frequency response if they are operating in a free sound field and are mounted on a tripod. On the other hand, personal sound exposure meters that have a pressure field microphone will have a flat frequency response if mounted on the user's body, both in diffuse and in free sound field.

This investigation does not use a personal sound exposure meter per se, but a pressure field microphone (B&K 4166) and a free-field microphone (B&K 4165), both connected to a B&K 2669 preamplifier.

The reference microphone used is a laboratory standard microphone B&K 4180 calibrated by

reciprocity (primary method) in pressure field and also in free-field. It is connected to a B&K 2673 preamplifier whose gain is determined by insert voltage.

The torso simulator used is a Kemar mounted on a turntable B&K 9640 with rotation of 60 seconds/ revolution. The rotating boom used is a B&K 3923 with a rotation of 16 seconds/revolution. The signal conditioner used is a B&K NEXUS. Two references sound sources B&K 4204 are used to provide the excitation sound signal in the diffuse-field.

The reverberation chamber used has 226 m³ volume and it was validated according to ISO 354 [5]. The anechoic chamber used has approximately 125 m³ volume and it was validated for microphone calibration in free-field by sequential comparison as described in the EURAMET.AUV.A-S2 comparison report [4].

4. PROCEDURE AND RESULTS

4.1 Procedure in reverberation chamber

According to IEC 61183 [3], to determine the sensitivity in a diffuse-field below 125 Hz the equivalent-continuous sound pressure level (L_{eq}) must be calculated with an averaging time greater than 15 min. In this investigation, the L_{eq} was calculated with an averaging time of 16 min. The excitation sound signal took place through two B&K 4204 reference sound sources positioned in opposite corners of the reverberation chamber thus yielding great homogeneity to the diffuse sound field. Figure 1 shows a sketch of the configuration with the rotating boom, which is the same when using the torso simulator.

4.1.1 Results in the reverberation chamber with torso simulator plus turntable

The first method studied was the sequential comparison in diffuse sound field with the reference microphone (B&K 4180) and the microphones under test (B&K 4166 or B&K 4165) mounted sequentially on the shoulder of the torso simulator, as shown in Figure 2.

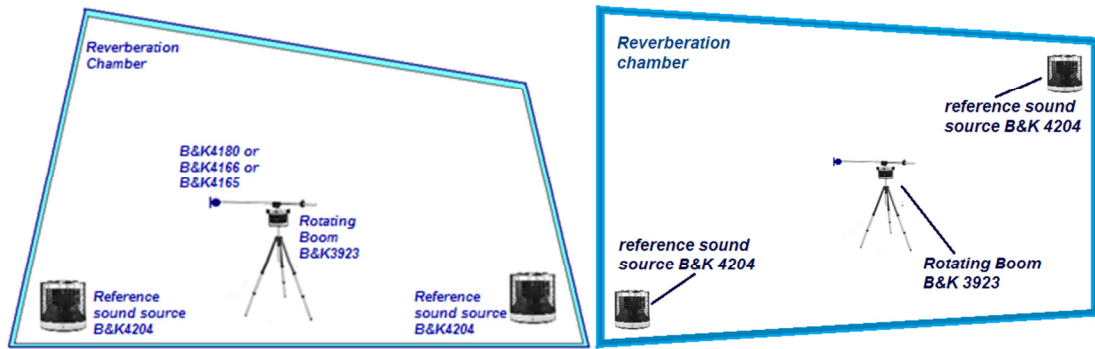


Figure 1: Sketch of the equipment configuration in the reverberation chamber with the reference sound source and the rotating boom: at the left side, lateral cut view, and at the right side, top cut view.

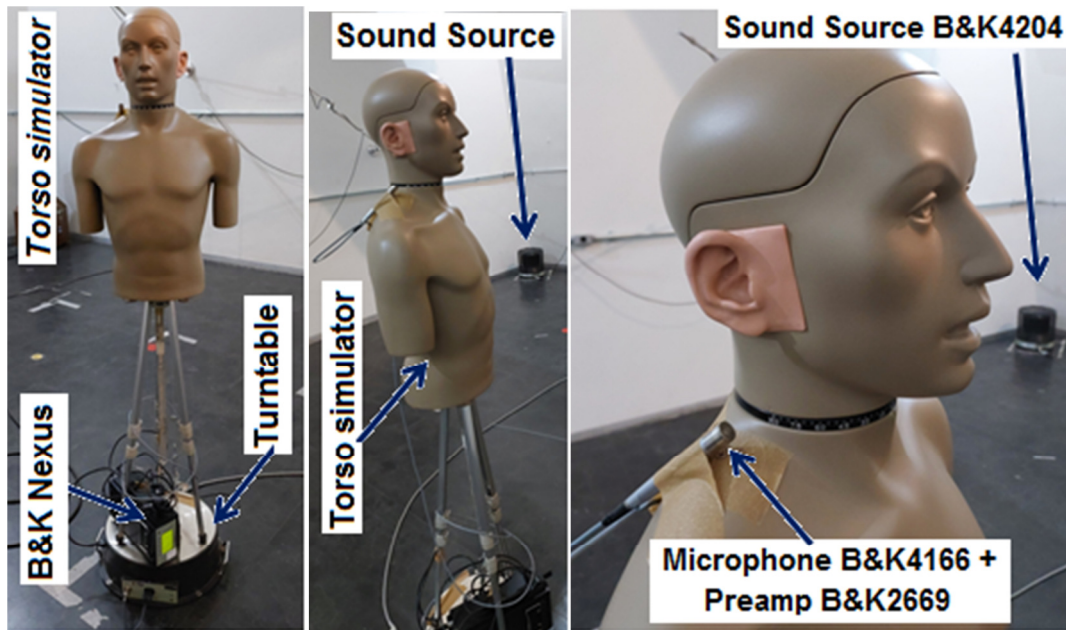


Figure 2: Photos of the sequential method configuration in reverberation chamber with torso simulator, signal conditioner, turntable, reference sound source, preamplifier and microphone under test.

The obtained sensitivities of the microphones under test (B&K 4166 and B&K 4165) were normalized at 1 kHz and the respective frequency responses are shown in Figure 3. The maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1 [6] also are presented.

4.1.2 Results in the reverberation chamber with rotating boom

The second method studied was the sequential comparison in diffuse-field with the reference

microphone (B&K 4180) and the microphones under test (B&K 4166 or B&K 4165) mounted sequentially in the rotating boom (B&K 3923), as shown in Figure 4.

The obtained sensitivities of the microphones under test (B&K 4166 and B&K 4165) were normalized at 1 kHz and the respective frequency responses are shown in Figure 5. The maximum and minimum tolerances permitted for class 2 sound level meters according to the IEC 61672-1 [6] also are presented.

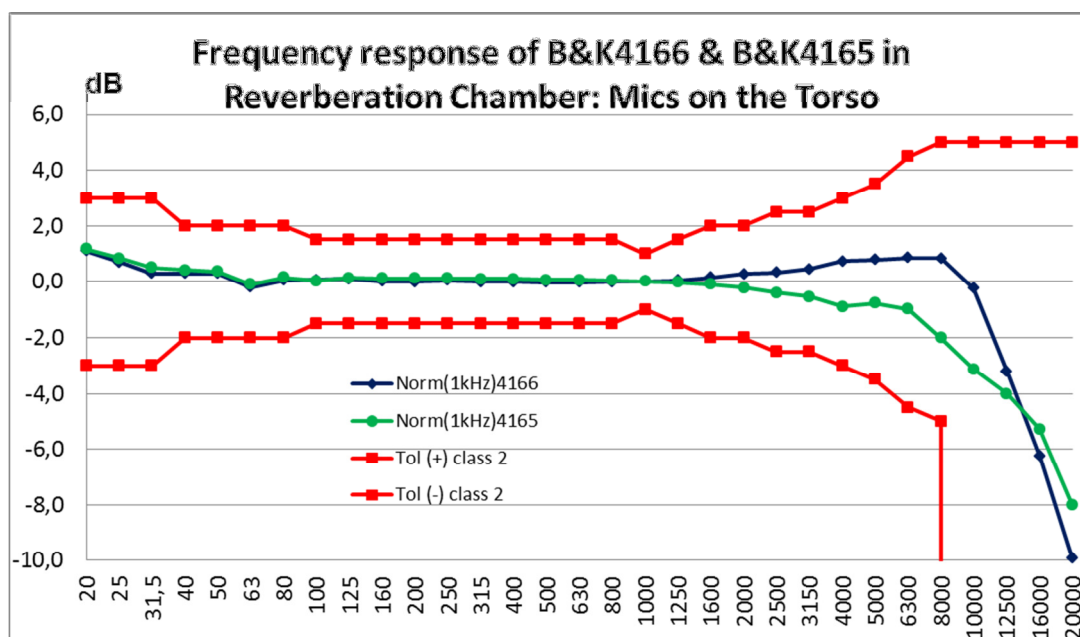


Figure 3: Sequential method configuration in reverberation chamber with torso simulator: Frequency response curves (normalized at 1 kHz) of the B&K 4166 (blue line - diamond) and B&K 4165 (green line - circle) microphones, as well as the maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1.

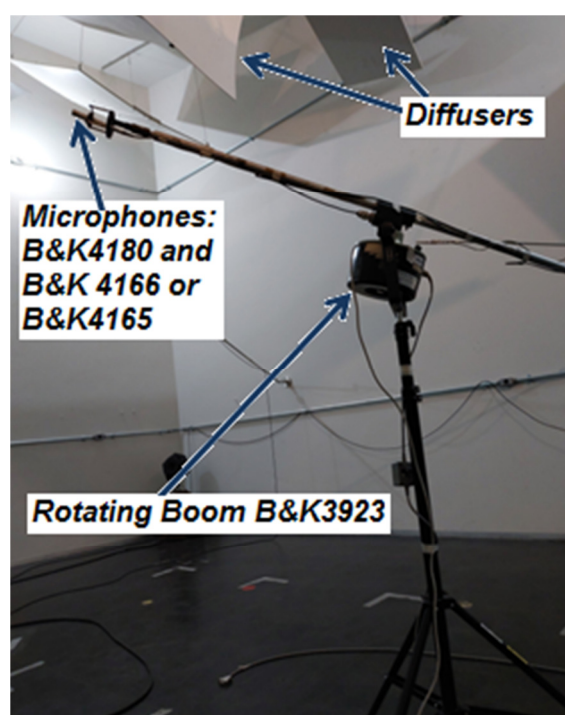


Figure 4: Photo of the sequential method configuration in reverberation chamber with rotating boom and reference microphone.

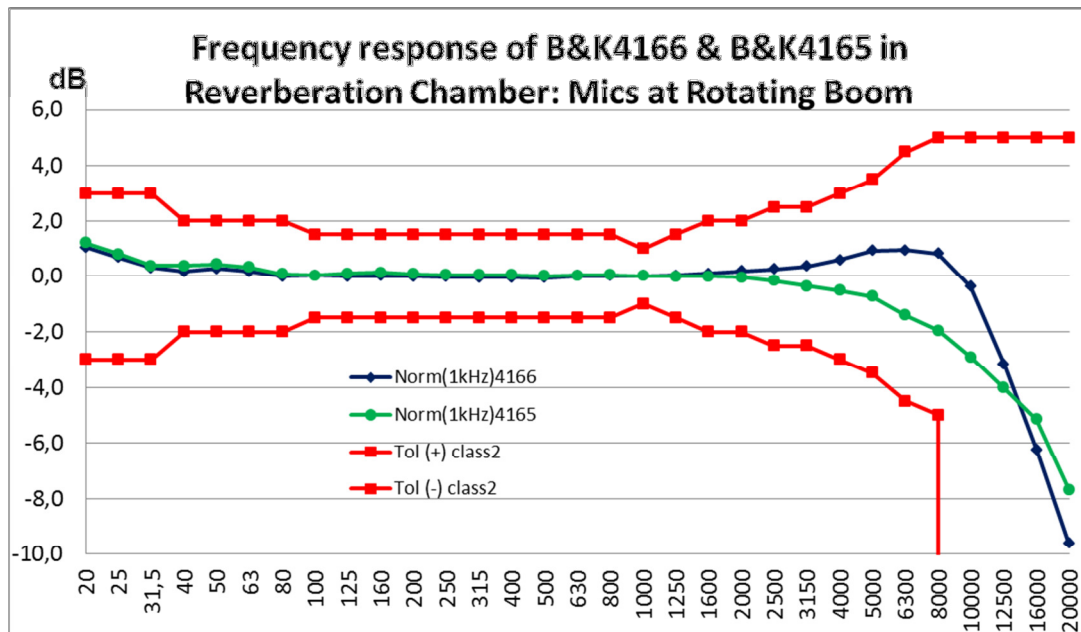


Figure 5: Sequential method configuration in reverberation chamber with rotating boom: Frequency response curves (normalized at 1 kHz) of the B&K 4166 (blue line - diamond) and B&K 4165 (green line - circle) microphones, as well as the maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1.

4.2 Procedure in anechoic chamber

The results in the anechoic chamber were obtained through three different configurations. The first configuration used the torso simulator mounted in the anechoic chamber in front of the loudspeaker and 1 m away from it. Both, the reference microphone (B&K 4180) and the microphones under test (B&K 4166 or B&K 4165) were mounted sequentially on the shoulder of the torso simulator (see Figure 6).

The second configuration used was the classic free-field sequential comparison according to IEC 61094-8 [7] and as described in the EURAMET.AUV.A.S-2 comparison report [4] (see Figure 8).

The third configuration used in this investigation was the one described in IEC 60118-8 [8]. According to this standard, the reference microphone (B&K 4180) is positioned 1 m from the loudspeaker (Figure 8) and on the center point of the torso simulator. The microphones under test (B&K 4166 or B&K 4165) were mounted on the shoulder of the torso simulator as shown in Figure 6.

4.2.1 Results in anechoic chamber with reference microphone and microphone under test mounted on the torso simulator

The measurement procedure used was the sequential mounting of the reference microphone (B&K 4180 – calibrated in a pressure field) and then microphones under test (B&K 4166 or B&K 4165) at 10 cm away the ear entrance canal, according to ISO 9612 [3]. The center of the coaxial loudspeaker is aligned with the nose of the torso simulator and is 1 m away from the center of the torso. Figure 6 shows the position of the torso simulator in the anechoic chamber, as well as the position of the microphones on the shoulder of the torso.

The obtained sensitivities of the microphones under test (B&K 4166 and B&K 4165) were normalized at 1 kHz and the respective frequency responses are shown in Figure 7. The maximum and minimum tolerances permitted for class 2 sound level meters according to IEC 61672-1 [6] also are presented.

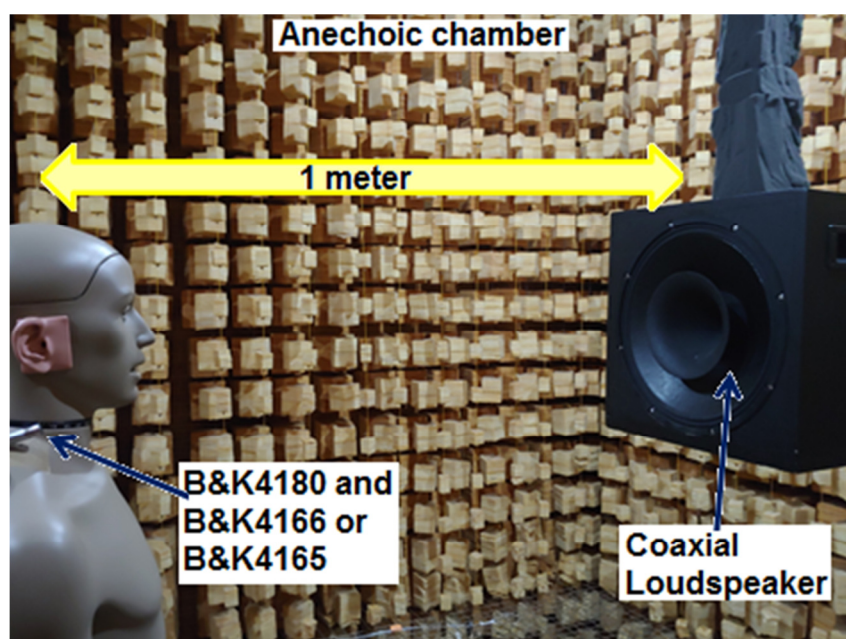


Figure 6: Photo of the sequential method configuration in anechoic chamber with torso simulator: Center of the torso simulator 1 m away from the coaxial loudspeaker. Reference microphone and microphones under test mounted, sequentially, on the shoulder of the torso simulator.

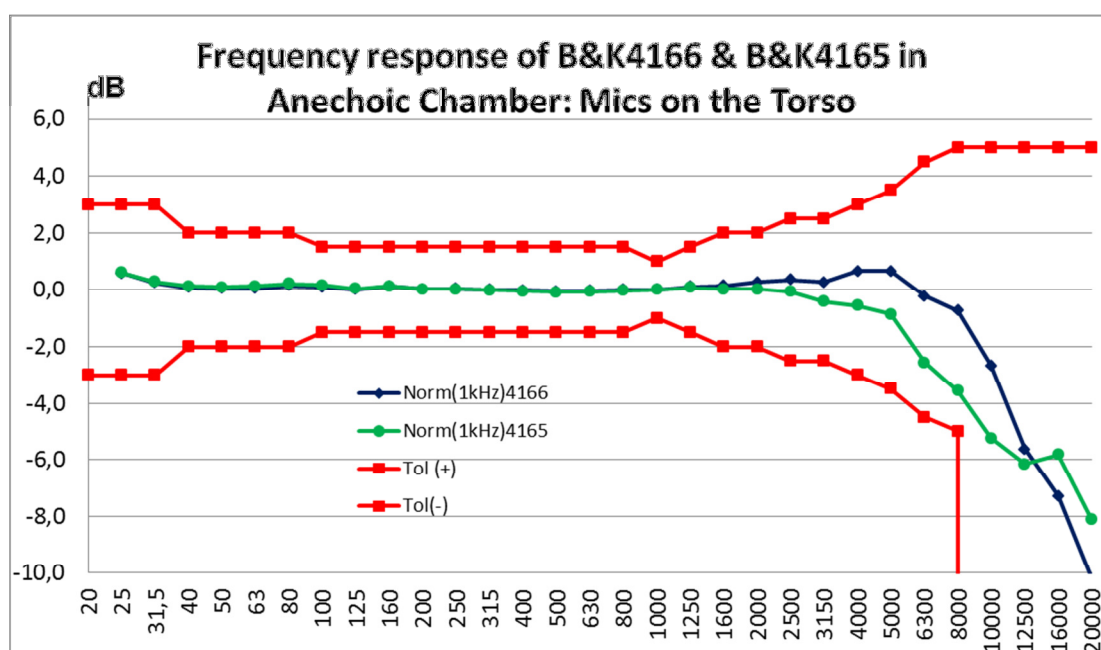


Figure 7: Sequential method configuration in anechoic chamber with torso simulator: Frequency response curves (normalized at 1 kHz) of the B&K 4166 (blue line – diamond) and B&K 4165 (green line – circle) microphones, as well as the maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1.

4.2.2 Results in anechoic chamber with reference microphone and microphone under test mounted on the positioning rod

This procedure was the classic sequential comparison method used both to calibrate

microphones (in accordance to IEC 61094-8 [7]) and sound level meters (in accordance to IEC 61672-2 [9]). The positioning of the reference microphone and the microphones under test were 1 m away from the loudspeaker, as shown in Figure 8.

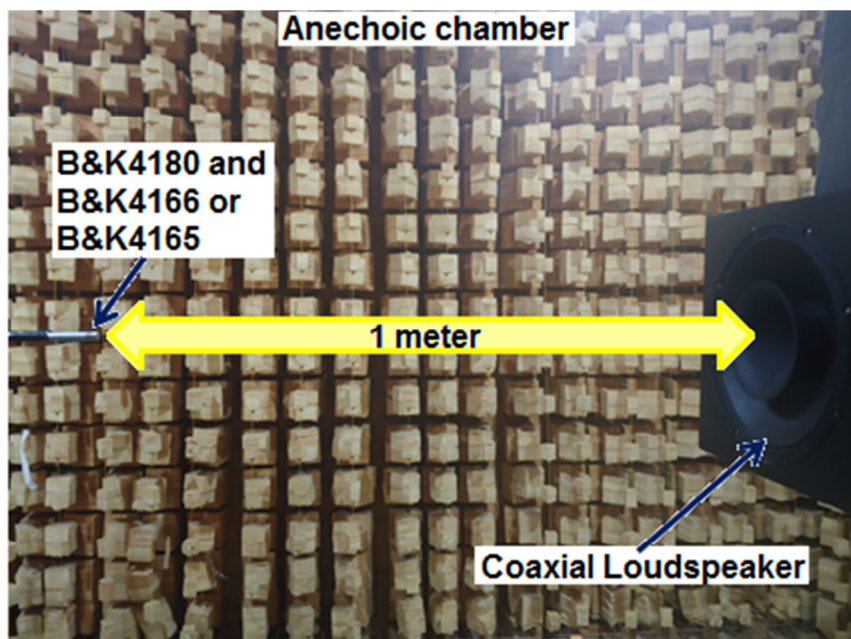


Figure 8: Photo of the sequential method configuration in anechoic chamber with positioning rod: Reference microphone and microphones under test positioned, sequentially, 1 m away from the coaxial loudspeaker.

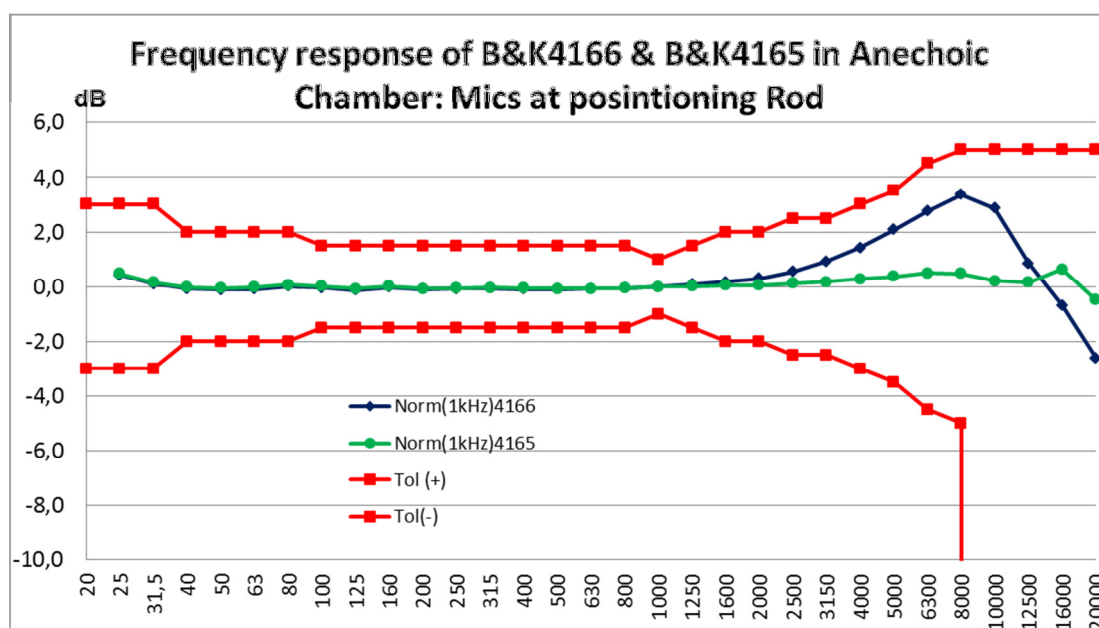


Figure 9: Sequential method configuration in anechoic chamber with positioning rod: Frequency response curves (normalized at 1 kHz) of the B&K 4166 (blue line – diamond) and B&K 4165 (green line – circle) microphones, as well as the maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1.

Figure 9 shows the obtained frequency responses normalized at 1 kHz of the microphones under test. The maximum and minimum tolerances permitted for class 2 sound level meters according to IEC 61672-1 [6] also are shown.



4.2.3 Results in anechoic chamber with reference microphone on the positioning rod and microphones under test on the torso simulator

This procedure for calibrating personal sound exposure meters was the closest to a true application. The configuration used for the measurement of the reference sound pressure level with the reference microphone is described in IEC 60118-8 [8]. The reference value of the sound pressure level was measured with the reference microphone (B&K 4180) in the center of the torso simulator (the reference point) and the microphones under test (B&K 4166 or B&K 4165) mounted on the shoulder of the torso simulator.

Figure 10 shows the results of measurements with the B&K 4166 and B&K 4165 microphones. The maximum and minimum tolerances permitted for class 2 sound level meters according to IEC 61672-1 [6] also are presented.

5. ANALYSIS OF RESULTS

This investigation aims to find a measurement method that more faithfully represents the results of a personal sound exposure meter used in the workplace. Therefore, the following analysis is focused on finding results that best represent measurements from a personal sound exposure meter mounted on a worker's body.

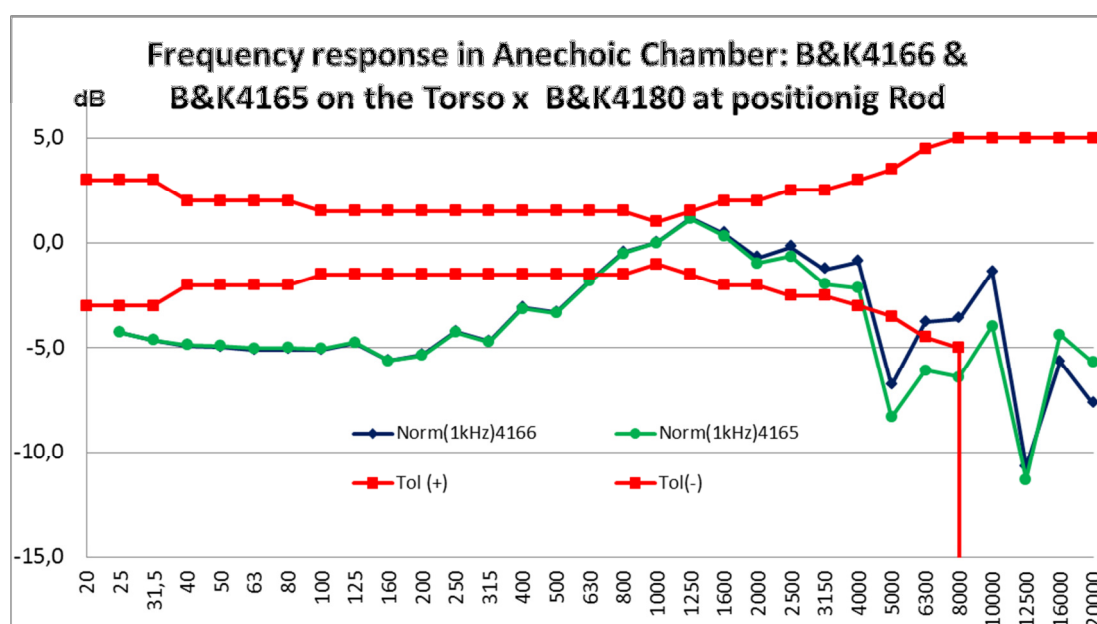


Figure 10: Sequential method configuration in anechoic chamber with torso simulator and positioning rod: Frequency response curves (normalized at 1 kHz) of the B&K 4166 (blue line – diamond) and B&K 4165 (green line – circle) microphones, as well as the maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1.

5.1 Analysis of measurements in the reverberation chamber

The first consideration to be presented is that, in Brazil, users of personal sound exposure meters mainly use them in an indoor work environment, so the diffuse sound field is the best approximation of this boundary condition. So, following this condition, when comparing the results obtained in the reverberation

chamber using the configuration with the torso simulator (Figure 3) and with the rotating boom (Figure 5) it is observed, in Figure 11, that there are no significant differences between the results obtained in both configurations. It is worth noting that the differences observed in Figure 11 are between the B&K 4166 (pressure field microphone) and B&K 4165 (free-field microphone) microphones.

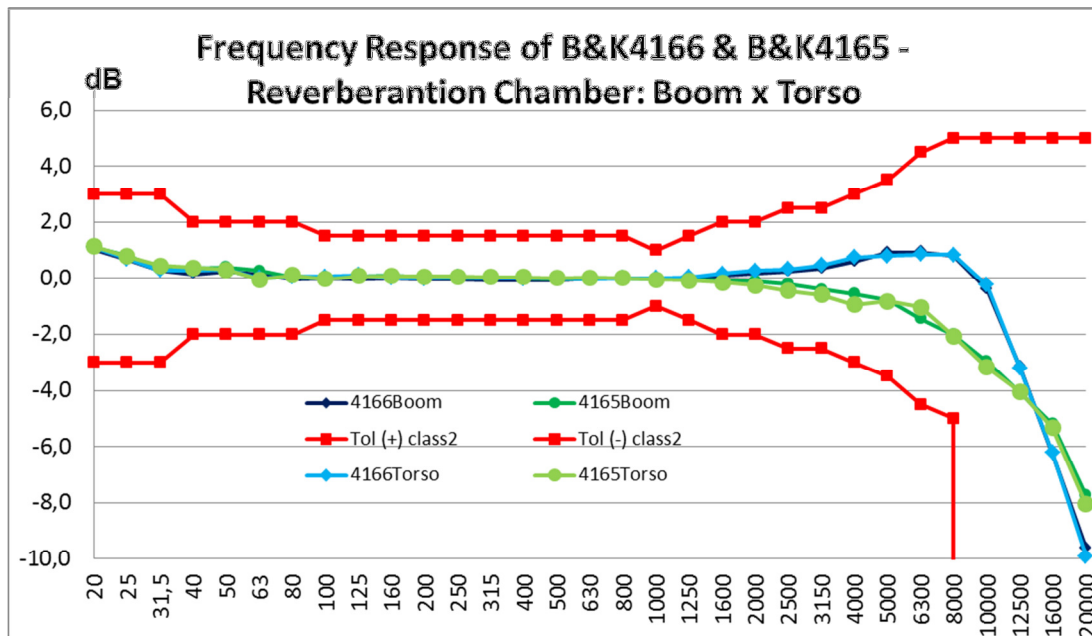


Figure 11: Sequential method configuration in reverberation chamber: Frequency response curves (normalized at 1 kHz) of the B&K 4166 and B&K 4165 microphones (on rotating boom and torso simulator), as well as the maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1.

From Figure 3, it is observed that the flat frequency response up to 10 kHz can only be obtained with the pressure field microphone (B&K 4166). Therefore, the personal sound exposure meter applied to an indoor work environment should use a pressure field microphone. The personal sound exposure meter that uses a free-field microphone tends to attenuate the noise to be measured at high frequencies when on the factory floor. However, it should be noted that both, pressure field and free-field, microphones would comply with the requirement for a class 2 sound level meter according to IEC 61672-1 [6].

5.2 Analysis of measurements in the anechoic chamber

There are cases where the worker spends the day working in outdoor environments, so pattern evaluation of the personal sound exposure meter with the closest configuration to their reality should be sought. In this case, the use of the anechoic chamber becomes fundamental in the possible configurations of the measurement procedures.

Analyzing Figure 9, the opposite of the analysis in subsection 5.1 is identified. When the personal sound exposure meter has a

pressure field microphone (B&K 4166) and its pattern evaluation is carried out in a free-field, probably at high frequencies, the risk of the personal sound exposure meter failing increases. On the other hand, a personal sound exposure meter with a free-field microphone (B&K 4165) will have its pattern evaluation more easily approved.

However, in the most real case, when the personal sound exposure meter is mounted on the body of the worker whose work environments is outdoor, then the results of Figure 7 shows that a personal sound exposure meter with a pressure field microphone (B&K 4166) has a flatter response than the one with free-field microphone (B&K 4165).

Figure 12 shows results with the reference microphone (B&K 4180) and microphone under test (B&K 4166 or B&K 4165) mounted on the shoulder of the torso simulator, and shows the results with the reference microphone and microphone under test mounted on the positioning rod.

From Figure 12 it can be observed that the frequency response curves are extremely dependent on the setup configuration. In the case of the configuration where the microphones are mounted on the positioning



rod, the incident sound wave is not disturbed, and therefore, the frequency response curve is better behaved. The same is not true in the configuration with the torso simulator. The

presence of sound reflections changes the frequency response curve of the microphones under test.

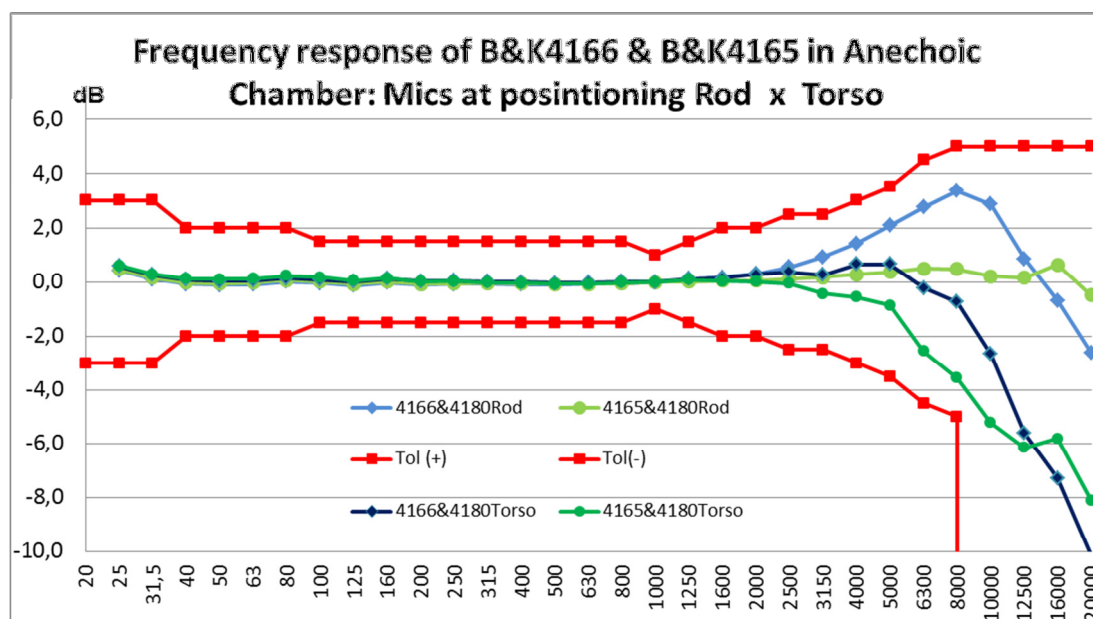


Figure 12: Sequential method configuration in anechoic chamber: Frequency response curves (normalized at 1 kHz) of the B&K 4166 and B&K 4165 microphones (on the positioning rod and torso simulator), as well as the maximum and minimum tolerances permitted for class 2 sound level meters according to IEC 61672-1.

5.3 Analysis of measurements in the anechoic chamber with microphone under test on the torso and reference microphone on the positioning rod

The results shown in procedure described in subsection 4.2.3 are the most realistic for those using personal sound exposure meter in outdoor work environments. The presence of sound reflections and diffractions caused by the torso simulator on the microphone of personal sound exposure meter in the frequency range from 400 Hz to 12.5 kHz is strongly noticeable. Measurements results in subsection 4.2.3 present such different behaviors from the others ones presented in free-field that, to some extent, it is difficult to normalize them at 1 kHz and keep results within the tolerances according to IEC 61672-1 for a class 2 sound level meter. Therefore, compliance with this requirement during conformity assessment becomes a very hard task. It is believed to be very difficult to create a new unique tolerance for this configuration, but, despite this inconvenience, it is important to emphasize here that this is the case that

comes closest to real life in outdoor work environments. Figure 13 shows the results with the reference microphone (B&K 4180) mounted on the positioning rod and microphones under test (B&K 4166 or B&K 4165) mounted on the shoulder of the torso simulator, and shows the results with the reference microphone and microphone under test mounted on the shoulder of the torso simulator.

Another important point in the revision of IEC 61252 is about the inclusion or not of the personal sound exposure meter directional response test. The measurement procedure for this test is the same as described in IEC 61672-2 [9] which seems strange since the real condition of use is not to be mounted on a tripod but on the shoulder of a worker. Considering this, the results of measurements in Figure 13 show that the worker's body (torso simulator) leads to sound reflections and diffractions that interfere with the frequency response curve of the personal sound exposure meter when the excitation sound source is at a zero degree incidence. Certainly, if

measurements were performed in additional angles between 0 and 360 degrees, the results

would be very different from the ones performed according to IEC 61672-2 [9].

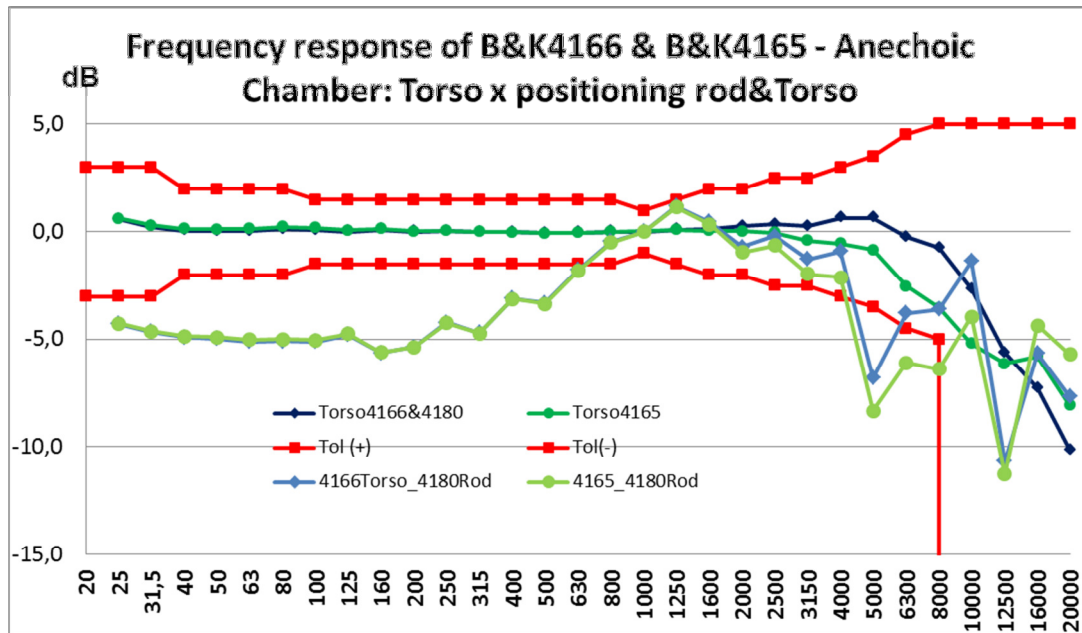


Figure 13: Sequential method configuration in anechoic chamber: Frequency response curves (normalized at 1 kHz) of the B&K 4166 and B&K 4165 microphones mounted on the torso simulator and B&K 4180 microphone mounted on the positioning rod. In addition, results with B&K 4166, B&K 4165 and B&K 4180 mounted on the torso simulator are shown. As well as the maximum and minimum tolerances permitted for a class 2 sound level meter according to IEC 61672-1 are shown.

6. CONCLUSIONS

The methods used in this study indicate that a personal sound exposure meter should be equipped with a pressure field microphone, because when mounted close to the body, it will present a pressure field behavior and not a free-field behavior.

Based on in this study for evaluating the acoustic performance of personal sound exposure meters in diffuse-field for the purpose of pattern evaluation, both the use of the torso simulator and the use of the rotating boom present similar results.

It is assumed that, in most applications, the use of personal sound exposure meter is in an indoor work environment. Based on this assumption, the use of reverberation chambers for the evaluation of acoustic performance of personal sound exposure meters should be mandatory in a current revision of IEC 61252.

Although IEC 61672-2 serves as a reference for the revision of IEC 61252, it is understood that the use of sound level meters in noise measurements is different from the use of personal sound exposure meters in the work environment. Sound level meter, in most applications, uses a tripod to perform the sound pressure level measurements, while personal sound exposure meter is fixed/mounted on the worker's body. In this case, the influence of the acoustic impedance of the body is significant, generating sound reflections and diffractions in the microphone of personal sound exposure meter. On the other side, the sound level meter is not impacted significantly by sound reflections from the tripod. Therefore, it is recommended that the evaluation of acoustic performance of personal sound exposure meters in free-field use the method of sequential comparison mounting the reference microphone and the personal sound exposure meter on the torso simulator and not as in the classical sequential comparison method.



Another conclusion of this investigation is that the directional response test for personal sound exposure meter should be further discussed regarding its need (if it is really necessary) and measurement procedure (using or not using a torso simulator).

It is worth emphasizing here that the proposals presented are intended exclusively for pattern evaluation and not for the periodic test of personal sound exposure meters.

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