CFA '18 LE HAVRE ▪ 23-27 avril 2018
14ème Congrès Français d'Acoustique

Sound power level measurement in diffuse field for not movable sources or emitting prominent discrete tones

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Determination of sound power level (Lw) using diffuse field is widely used in industry and certification, especially for heating, ventilation and air conditioning (HVAC) machines. A hard-walled or reverberation test room is less expensive to build than anechoic or hemi-anechoic rooms and it is suitable to manage the large range of ambient conditions required for air-conditioning units. The associated international standards are ISO 3741 (precision, grade 1), ISO 3743-1, ISO 3743-2 (engineering, grade 2) and ISO 3747 (survey, grade 2 or 3). In practice, laboratories (and industrials) face difficulties to carry out tests at grade 1 and even grade 2 because many machines have spectra with discrete-frequency components (pure tones) at either low or medium frequencies with a possible impact on the A-weighted level. The qualification of the room according to Annex D of ISO 3741 is not always possible. Then, the sound measurement of those sources requires several microphones and source positions which may be unrealistic. In addition, many kind of machines cannot be moved (wall hung boilers, fans, ducted HVAC units). Their noise measurement according to ISO 37431 also requires source moving if the machines have large directivity or discrete-frequency components. For this purpose, the standard title includes “small, movable sources”. Despite these constraints, some product standards (e.g. ISO 13347-2) allow the use of ISO 3743-1/2 even if the machines are not movable, accepting a result bias to improve reproducibility. This paper illustrates these difficulties, with actual examples encountered by the authors. Various options are studied to improve the situation. For instance, the possibility to merge the different standards with a system of more or less severe criteria is evaluated, the accuracy grade becoming a consequence of the used means and the obtained uncertainty result.

1 Introduction

Several product standards describe how to install the unit under test, usually according to a typical real installation. On the other hand, high reproducibility is a request of the standards which leads to precisely define the installation parameters, as for example the distance between the wall and the tested unit, or duct length, or material used. In addition, it often occurs that some units can only be installed in one position and are not movable:

- Wall hung boilers, for which a flue takes place inside the reverberant room,
- Heat pumps, chillers or ventilation units, or all units with a fan that require to be ducted on the air suction side, discharge side or both sides.

The related standards are:

- Wall hung boilers: EN 15036-1
- Heat pumps, chillers, hot water heat pumps: EN 12102-1 and prEN 12102-2
- Ventilation systems: EN 13141-4, EN 13141-7
- Fans: ISO 13347 series

In these standards, the length of the duct is fixed or bounded by definite lengths. Moving the unit is then impossible, unless by changing the length or the angle of the ducts. Moreover, the ducts bring some pressure drop that has an impact on the operating point of the fan/unit. Changing their length would change the air flow rates inside the machine and then the resulting noise.

If the unit exhibits some tonal bands requiring a specific action for ISO 3743-1/2 or ISO 3741 standards, and if the qualification of the room according to ISO 3741 Annex D did not succeed, the unit cannot be moved inside the room. No alternative solution is proposed by the standard nor a method to correct the measured value.

2 Current situation of standards

The most recent draft for the revision of ISO 3740 standard [7] is the best summary of the different standardized methods about sound power level measurements in reverberant fields.

The table below allows comparing these methods. It is based on a table from the draft standard modified to show more clearly the constraints and the relations between movability and the discrete-frequencies / tonal bands of the sources.

Parameter	ISO 3741		ISO 3743-1	ISO 3743-2	ISO 3747
Grade of accuracy	Precision		Engineering	Engineering	Engineering or survey
Test environment	Reverberation test room		Hard-walled room	Special reverberation test room	Essentially reverberant field in situ
Requirements on test environment	Room volume and reverberation to be qualified		Volume 40 times > than reference box volume Volume ≥ 40 m³ Absorption coef. ≤ 0,20	70 m³ ≤ volume ≤ 300 m³	Annex A Excess of pressure level ≥ 7 dB
Volume of source under test	Preferably less than 2 % of test room volume		Preferably less than 1 % of test room volume	Preferably less than 1 % of test room volume	No restrictions; limited only by available test environment
Character of noise from the source	Steady, broad-band	Steady, narrow-band or discrete frequency	Any, but no isolated bursts (1)	Any, but no isolated bursts	Steady, broad-band, narrowband or discrete frequency
Room qualification	At least 6 SSR positions for broadband spectrum	Annex D See 4.1 in this paper	Limits on standard deviation of reproductibiliy of a directional source	Requirements on differences between SSR calibration and measurement	Nothing on the whole room but a weak requirement on used part of the room
Movability inside the room	Not necessary	Position numbers depending of dispersion No limit number	1, 2 or 2+2 in another room	3, 6 or 12 source position	No The SSR may be measured in 4 position.
Limitation for background noise	See ISO 3740				
Instrumentation	Class 1				
Other parameters	See ISO 3740				

(1) *The aural examination is used to determine the source directivity and the possible discrete tones in the emitted noise.*

3 Movability of unit

The standards use two source movability characteristics. The first one is the opportunity to move the source (unit) in a test room (ISO 3741 and ISO 3743-1 and 2). If it is not possible to move the unit and if the room is enough reverberant, the ISO 3747 may be used … but it clearly mentions that it has not to be used in a laboratory. Our purpose is not to discuss this ISO 3747 standard except to focus on a wider use of this method in reverberant laboratory rooms. The second movability is the possibility or the obligation to move the source inside the test laboratory room (ISO 3741 and ISO 3743-1 and 2). When the sound of the tested source contains significant discrete-frequency components, measurement problems arise. To obtain the needed averaged values, to smooth and to reduce the unfavorable behavior of the room-source couple, a way is to move the tested source.

Despite its importance, this specificity is not listed in the ISO 3740 table.

Figure 1 shows an example of a unit producing discret tones and moved in 5 positions in a 200 m³ reverberant room. The sound power level highly varies, especially at low frequency. The overall values go from 48.7 to 55.1 dB(A). This proves that moving the unit is important to get a correct result. Unfortunately, in many cases, it is not possible to move the unit in the room, and if the room is not qualified according to ISO 3741 – Annex D, there is no other possibility offered by the standards to perform the test.

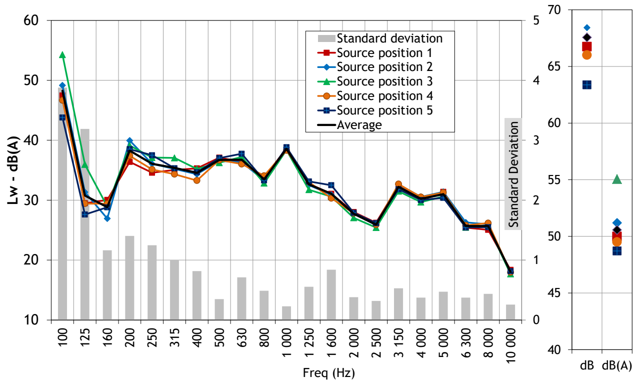

Figure 1: Sound power level of a unit producing discrete-tones, in 5 positions in a reverberant room, and the resulting standard deviation.

4 Qualification for tonal bands according to ISO 3741

4.1 Methodology

The ISO 3741 standard defines a method to determine if the room is suitable for the sound power level measurement of machines producing noise with high level of tonality or single frequencies.

It consists of the emission of 365 pure frequencies by a loudspeaker (approx. 20/25 frequencies for each one-third frequency band between 100 and 2500 Hz). Then, the spatial and time averaged sound pressure level is measured in the reverberant room as well as the loudspeaker near-field response which is used to correct the sound pressure in the room. The standard deviation of the sound pressure level on the 20/25 frequencies must be lower than values given in the table D.1 of annex D (from 3 at 100 Hz to 1.5 à 2500 Hz).

A low standard deviation ensures that for any tonal band, the average sound pressure level of the associated one-third octave will be correctly transcribed by the room. It allows performing measurements for all kinds of products, regardless the spectrum components.

If this qualification is not successful, the operator has to calculate, according to standard deviations deduced from initial measurements in 6 microphone positions, the number of microphone and product positions to be used in order to comply with the ISO 3741 standard.

4.2 Sensitivity to the positions

The room must be qualified for the usual positions of the unit under test. An issue is that the real position of the noise source cannot be known precisely. For example, the dimensions of the outdoor unit of a heat pump can be 1.6 x 1 x 0.6 m (or bigger or smaller). The unit includes a fan which can generate two peaks for the rotation speed and the blade passing frequencies, and a compressor which generates peaks harmonics of its rotation speed (approx. 48 Hz for steady operation and between 30 to 90 Hz for inverter type units). These two local sources are not at a single location. In such a case, determining the position of the source is difficult, whereas the tonal band qualification requires a definite position of the loudspeaker. The experience shows that this location has a great influence on the qualification.

Figure 2 shows the standard deviations from five successive qualifications of the same room in a short time period. The loudspeaker is on the floor at a P0 position, and 4 others positions in the 4 cardinal positions, at 50 cm distance. The differences between the five qualifications are important (e.g. from 1.5 to 2.6 at 315 Hz). This shows the sensitivity of the qualification process to the way it is achieved.

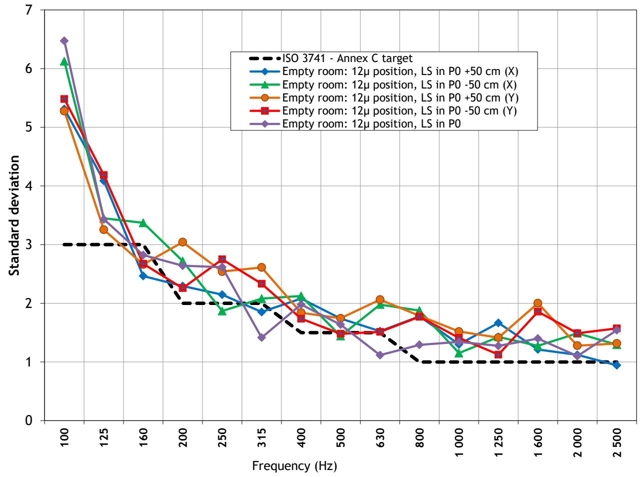

Figure 2: Standard deviation from Annex D for 5 positions of loudspeaker, ± 50 cm in 4 directions.

With these differences, it is difficult to be sure that the qualification, which can be successful in one position, can be extended to several positions of the loudspeaker. The consequence on the unit position is not known, as their real acoustic location(s) is not so well defined than the position of a small loudspeaker.

4.3 Improving the room

Following the main recommendations of the standard (recommended ratios of the room dimensions, non-parallel walls, some damping, etc.) does not fully guarantee that the room fulfills the requirements of the qualification. If necessary, the room can be improved by increasing the damping to soften the modes (but not too much to keep the room reverberant), or by increasing the diffusivity.

Implementing the modal damping can be tricky as it has an influence on the way to work in the room. Lower reverberation time means that the minimum distance between the source and the microphone dramatically increases. A 220 m³ room with 4.5 m height means 48 m² of floor area, for example 8 x 6 m. Microphones cannot be located at less than 1 m from wall, meaning a 6 x 4 m remaining area. The minimum distance between the product and the microphone for a reverberation time of 3 s is 1.4 m (see §8.3 in [9]). For configurations with high tonal bands, it is recommended to decrease the reverberation time to 2.2 s at 100 Hz, leading to a minimum distance of 1.64 m.

If the qualification is not successful, the calculation may require up to 24 microphone positions, and more than 5 product positions (with at least λ/2 distance). How to move the product and the microphone with all these constraints in a so small available space?

The ISO 3741 standard indicates that rotating diffusers are suitable. It presents the successful case of a 5 m diameter diffuser, which seems quite big for the common 220 m³ rooms. The literature does not give other examples of rotating diffusers. The authors tried smaller diffusers (2 x 1 m) but their efficiency is not high enough to deeply modify the behavior of the room. The standard should give more helpful information to the user.

5 Improving the standards

5.1 Grade vs uncertainty?

The three standards ISO 3741, ISO 3743-1 and ISO 3747 give opportunity to perform measurement according to three grades (laboratory, engineering, survey), which are related to three expected uncertainty levels. The laboratory method is more demanding in terms of design and environment of the reverberant room, and implementation of measurement method. It should then produce results with a lower uncertainty than the two other grades. ISO 3741 and ISO 37431-1 provide different values for the reproducibility standard deviations for overall dB(A), respectively 0.5 and 1.5, but the values given for the frequencies are the same.

The uncertainty is the real criterion of measurement quality. Of course, if the conditions are good (broadband noise without background correction, etc.), ISO 3743-1 (grade 2) and ISO 3741 (grade 1) measurements will lead to the very similar overall calculated uncertainties. However, the measurements will not have the same grade just because the implemented standards have not the same grade. This is confusing.

In some cases, the uncertainty of measurements according to grade 1 method will be high because of bad conditions (tonality of the noise source, background noise correction, etc.). This means that the grade level does not guarantee an uncertainty level. The uncertainty calculated for each product under test is a better quality criterion than the grade. The grade is presently a symbol of implemented method, whereas it should be the consequence of the uncertainty.

If a product with complex noise, measured according to ISO 3741, leads to a ± 4 dB(A) uncertainty, is it really better than a broadband noise source measured according to ISO 3747 with ± 1 dB(A)? The answer should be no, even though the ISO 3741 grade 1 is better than the grade 3 of ISO 3747.

This grade gives an easy way to identify what effort has been done in the implementation of the measure. The grade 1 being more demanding than the grade 3, it should be able to perform measurements with more complex conditions. Its use is suitable for complex sound sources.

5.2 Towards an integrated standard?

The ISO 3740 standard is designed to choose the right method according to the available room and the product. Unfortunately, not all parameters are known before starting the noise measurement of a product. If the use of ISO 3741 proves impossible due to a parameter not fulfilling the requirements (e.g. tonality), it is not easy to move to a lower-class method such as ISO 3743-1 because there is no direct link between the two texts, even though the methods are close (comparison method). It would be useful to have only one standard for diffuse field measurements, allowing bridges at several levels.

The perfect standard would propose a unique methodology (the comparison method is probably the best choice), with gradual requirements levels for the main parameters:

- Instrumentation, and especially the reference sound source and its calibration,
- Background noise correction,
- Qualification of the diffusivity of the room, to define the number of microphone positions,
- Tonality of the source: definition of a criterion to determine if the source exhibits tonality, definition of a procedure to qualify the room. If the source cannot be moved, assessment of the consequences on the resulting uncertainty according to the values obtained during the qualification.

The requirements on each parameter could be adjusted according to several levels associated to uncertainties (laboratory, engineering, control). If the most severe requirement cannot be fulfilled, the user can move to the next one (lower). This allows a soft way to fulfill the best requirement possible, whatever the product under test.

The issue is then to make a synthesis of all these parameters to build a final uncertainty. This means that the grades should disappear in their present form to be replaced by a class labeling related to the measurement uncertainty.

Note: if some values of the spectrum do not fulfill the requirement, a procedure should exist to check if this has an influence on the overall dB(A) value, in the same way that presently done for background noise correction in ISO 3741.

Références

[1] EN 15036-1 (2006) – *Heating boilers. Test regulations for airborne noise emissions from heat generators. Airborne noise emissions from heat generators*

[2] EN 12102-1 (2017) – *Air conditioners, liquid chilling packages, heat pumps, process chillers and dehumidifiers with electrically driven compressors. Determination of the sound power level. Air conditioners, liquid chilling packages, heat pumps for space heating and cooling, dehumidifiers and process chillers*

[3] prEN 12102-2 (2017) – *Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors. Determination of the sound power level. Part 2. Heat pump water heaters*

[4] EN 13141-4 (2011) – *Ventilation for buildings. Performance testing of components/products for residential ventilation. Fans used in residential ventilation systems*

[5] EN 13141-7 – *Ventilation for buildings. Performance testing of components/products for residential ventilation. Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings*

[6] ISO 13347-2 – *Industrial fans -- Determination of fan sound power levels under standardized laboratory conditions -- Part 2: Reverberant room method*

[7] ISO/DIS 3740 (2017), *Acoustics – Determination of sound power levels of noise sources – Guidelines for the use of basic standards*

[8] ISO 3741 (2010), *Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for reverberation test rooms.*

[9] ISO 3743-1 (2010), *Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for small movable sources in reverberant fields – Part 1: Comparison method for a hard-walled test room*

[10] ISO 3743-2 (2018) –*Determination of sound power levels of noise sources using sound pressure -- Engineering methods for small, movable sources in reverberant fields -- Part 2: Methods for special reverberation test rooms*

[11] ISO 3747 (2010), *Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering/survey methods for use in situ in a reverberant environment*

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