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Practical comparisons of ISO 3744 and ISO 3745 Sound Power standards for automotive compressor testing

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ABSTRACT

As known in the industry, ISO has two specifications for computing Sound Power from sound pressure data measured in a laboratory environment: ISO-3745, a precision method and ISO-3744, an engineering method. The two specifications differ in a variety of ways including the qualification procedures for the test environment. In this paper, the authors provide a quick synopsis of the major differences between these two standards from the standpoint of the room qualification procedures and their impact on compressor data validity and portability. Comparison of room qualification testing strategies will also be provided with recommendation for ways to speed up the test, and analyze and display the data.

1. INTRODUCTION

The ISO3744 and ISO3745 specifications are part of the ISO 3740 series of specifications that define methods for determining sound power levels of various types of equipment from measurement of sound pressure. ISO3745 is a precision method and ISO3744 is an engineering-grade method. Both require free field or a free field over a reflecting plane environment, which means that the test has to be conducted in a fully anechoic or a hemi-anechoic chamber.

An automotive compressor manufacturer had to ensure that its sound power test setup complied with ISO standards. This required verifying that the interior of the sound chamber (Figure 1) satisfied the test room requirements for either ISO 3745 (preferred) or ISO 3744.

There are two main requirements for the acoustic environment according to either ISO 3745 and ISO 3744:

1. Free Field Adequacy (FFA) of the test room
2. Background noise

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While the requirement for background noise depends on the level of the noise of the source under test, the criterion for the FFA of the test room is independent from the source that will be tested inside it. For FFA of the test room, both standards aim at defining the admissible deviations from an ideal free field or a free field over a reflecting plane environment. By verifying that the test room does not deviate "much" from a theoretical acoustic free-field, the computed sound power is a very close approximation to the true sound power of the source.

Figure 1. Sound chamber at Michigan Automotive Compressor

2. TEST ROOM REQUIREMENTS FOR ISO3745 AND ISO3744

A. Test Room Requirements in ISO3745

Free field adequacy of test room

The general criterion for the test room itself, regardless of the source under test, is described in Annex A [1] . The idea is that of comparing the decrease of sound pressure with distance from a test source in the room to the expected decrease of sound pressure in a true free-field condition (i.e. sound pressure dropping with the inverse square of the distance). The test source has to approximate a point source, be relatively omni-directional and generate sufficient output that its level at the farthest corners of the room is at least 10 dB above background noise. With the test source emitting random noise, measurements are made at multiple microphone locations along a minimum of five straight paths away from the geometric center of the source to the room corners. Traditionally, this has been done by recording sound pressure from a microphone slowly moving away from the source on each line. Using modern equipment including multiple channel data acquisition capabilities, it is much more efficient to acquire data simultaneously from multiple microphones. Figure 2 shows one of the "telescopic" microphone traverses that were used for the ISO3745 room qualification procedure for the sound chamber in Figure 1.

The measured sound pressure drop with distance from the source is then compared to the theoretical drop (6dB per doubling of distance) from a point source in a free field and the difference has to be less than the values provided in Table 1. In case this difference exceeds the maximum values in the Table, other standards have to be used, that is either ISO 3744 or ISO 3746 (sound pressure-based) or ISO 9614-1 or ISO 9614-2 (sound intensity based).

Type of Test Room	One-third Octave band (Hz)	Allowable deviations (dB)
Anechoic room	< 630	1.5
	800 to 5,000	1.0
	> 6,300	1.5
Hemi-anechoic room	< 630	2.5
	800 to 5,000	2.0
	> 6,300	3.0

Table 1. Allowable deviation from the measured sound pressure levels from the calculated values based on the inverse squared law.

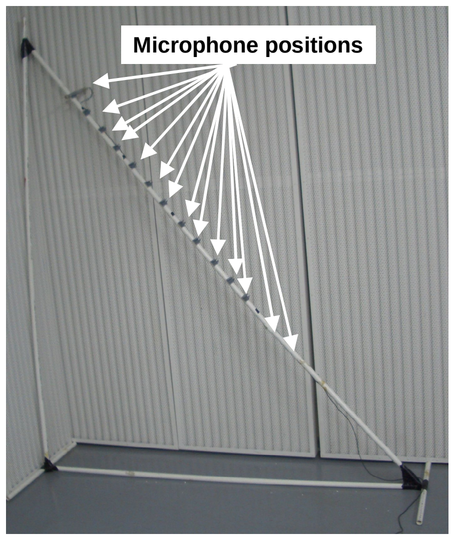

Figure 2. Microphone Traverse used for ISO3745 Test Room qualification

An alternative qualification procedure is provided in Annex B, which assesses the "free-field" quality of the test room with the specific source under test. Microphones are positioned on two measurement hemispheres of different radii, centered at the source under test. With the source under test operating, the average sound pressure over the microphones on the inner hemisphere S_1 and on the outer hemisphere S_2 are computed and used in the following formula:

$$\delta = L_{p1} - L_{p2} - 10 \log (S_2/S_1) \text{ dB} \qquad (1)$$

where:
L_{p1} is the average sound pressure level on surface 1 (S_1), in dB
L_{p2} is the average sound pressure level on surface 2 (S_2), in dB

If the value of δ is less than 0.5 dB in each frequency band, then the room qualifies for ISO 3745 when testing the specific source used for the qualification procedure of Annex B (conditional compliance).

Background Noise
At any measurement position and in each frequency band, the level from source has to be at least 10 dB above background noise level.

B. Test Room Requirements in ISO 3744

Free field adequacy of test room

The general criterion for the test room itself, regardless of the source under test, is described in Annex A. Possible test environments are a semi-anechoic room, an outdoor space and an ordinary room, provided that the requirements in Annex A are satisfied. The procedures described in Annex A use the environmental correction factor K_2, which is basically the difference between the test room and a true acoustic free-field. ISO 3744 is satisfied if $K_2 \leq 2$dB in each frequency band. Two types of qualifying procedures are included in Annex A:

- The absolute comparison test, which measures the sound power of a Reference Sound Source (RSS) in the test and compares it to its calibrated sound power value.
- The room absorption methods, in which K_2 is calculated from direct or approximate measurement of the sound absorption in the room.

Background Noise

Averaged over the microphone positions on the measurement surface, the level of background noise has to be, in each frequency band, at least 6 dB below the level of the source under test. If the delta between source and background noise is larger than 10 dB, no correction to the measured levels is required. However, if the delta is between 6 and 10 dB, the measured levels have to corrected by K_1, as described in section 8.3 of ISO 3744.

3. QUALIFICATION OF SOUND CHAMBER FOR AUTOMOTIVE COMPRESSORS

A. Test Room Qualification per ISO 3745

Testing was initially performed in accordance to ISO 3745:2003(E), which was the preferred standard. During the chamber qualification a sound source was placed on the floor in the center of the room and was used to broadcast white noise over a frequency range of 100-10,000 Hz. Measurements were taken along five traverses, one traverse directed from the center of the source to each of the four upper corners and one traverse directed from the center of the source in the vertical direction. Twenty measurements were taken along each of the four corner traverses and 16 measurements were taken along the vertical traverse, with all measurements spaced by 10 cm.

The deviations from free-field behavior were computed for each one third-octave band from 100 Hz to 10 kHz. The data for the 125, 500, 1000 and 2000 Hz are shown in Figures 3, 4, 5 and 6. As it can be clearly seen, the ISO 3745 maximum allowable deviation (indicated by the horizontal dotted lines) is exceeded at 125 Hz at larger distances from the source (d > 1.5m) while the behavior of the higher frequency bands complies with the ISO 3745 requirement. The larger deviation in the proximity of the boundaries at lower frequency is explained by the presence of significant reflected waves that are not absorbed by the acoustic treatment on the walls. These could also be room acoustic cavity modes triggered by the source excitation in the center of the floor. It is important to note that while the ISO 3745 standard prescribes a central position of the test source, in reality the automotive compressor cannot be located in the middle of the room, as it has to be driven via a belt by an external driveshaft, and with suction and discharge lines connected to a load stand outside the test room.

The background noise requirement was evaluated by comparing the level of the quietest compressor (run at low rpm) to the highest background noise seen in the test chamber, shown in Figure 7.

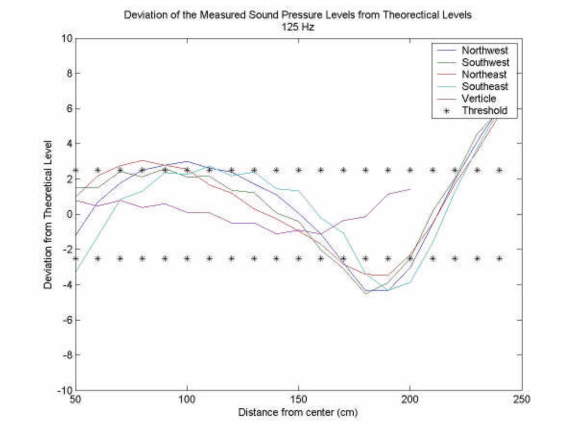

Figure 3. Deviation from inverse square law behavior – 125 Hz band

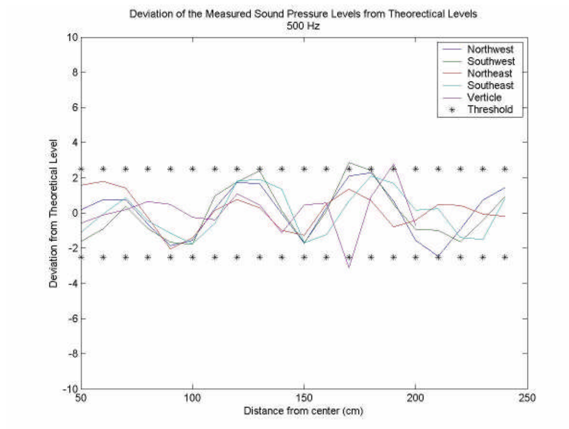

Figure 4. Deviation from inverse square law behavior – 500 Hz band

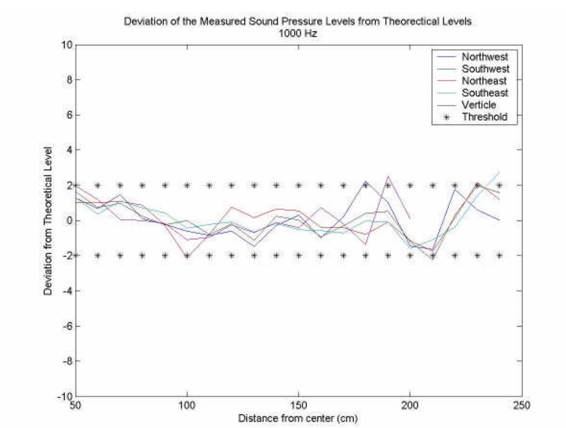

Figure 5. Deviation from inverse square law behavior – 1000 Hz band

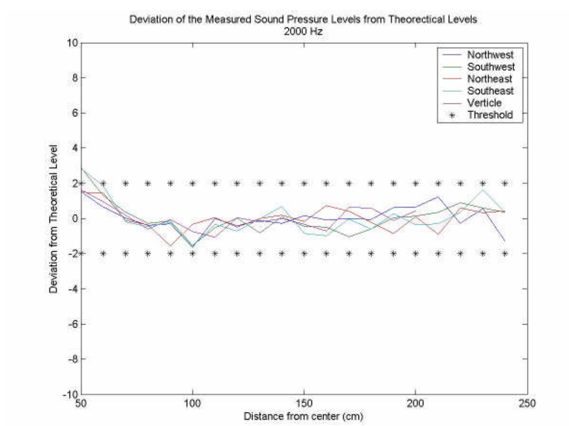

Figure 6. Deviation from inverse square law behavior – 2000 Hz band

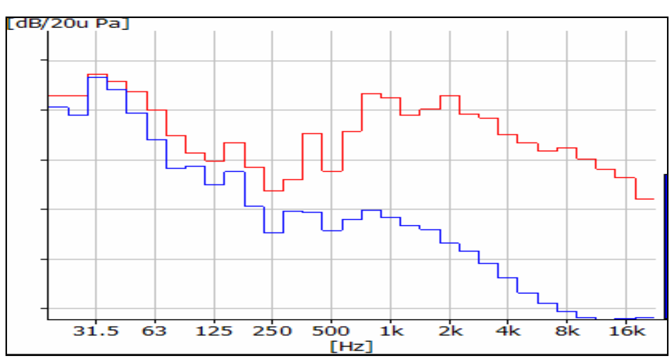

Figure 7. One third-octave frequency spectrum of quiet compressor at low RPM (red) and background noise (blue)

The conclusion of the investigation were:

a) The sound chamber complies with the free sound field requirement in the frequency range of 500 – 10,000 Hz at a distance of 1 – 1.5 meters from the center of the room. This assumes that the source is placed in the center of the room, as recommended by ISO 3745:2003(E).

b) The background noise requirement is verified only for f > 500 Hz.

Due to the dimensions, both internal and external, of the sound chamber, and to the lay-out constraints of the belt-driven compressor, it would have not been possible to achieve compliance to ISO3745 with any possible modifications. It was therefore decided to qualify the room per ISO 3744.

B. Test Room Qualification per ISO 3744

The lay-out constraints of the automotive compressor test setup can be accommodated by ISO 3744 by utilizing the "corner method" (Fig. C8 in App. C of the standard). A corner around the compressor, located off-center in the room, was realized by mounting three perpendicular surfaces of low sound absorption. It is important to observe that the dimensions of the walls which make the corner are set by the requirement (A.2.1 "Properties of reflecting planes") that they have to extend at least $\lambda/2$ beyond the projection of the measurement surface on the planes for the lowest frequency of the frequency range of interest. Due to the internal dimensions of the test room and to the dimension of the measurement surface, the dimension of the corner surfaces impose a minimum valid range of 200 Hz. This turned out to be the most important limiting factor for the qualification according to ISO 3744.

With this test setup, the following requirements were verified:
a) Similarity to free-field (i.e. amount of sound absorption present)
b) Background noise

As regards to condition a), ISO 3744 allows a 2 dB difference between free-field and test room in each frequency band (correction factor K_2). A correction factor K_1 is also used in case the difference between product and background noise is less than desirable. In other words, the requirements for adequacy of the test room in ISO 3744 are less stringent than those in ISO 3745. The sound absorption in the test room was assessed by measuring the reverberation time. The environmental factor K_2 was found to be less than 2dB in all bands from 125 to 8000 Hz.
As for the requirement for background noise, this was derived by:

- measuring the third-octave frequency spectrum of a very quiet compressor at the lowest RPM and subtracting 10 dB from it
- comparing the resulting spectrum to the highest measured background noise.

The compliance of the test room to the background noise requirement is shown in Figure 8. Correction is required for differences of 6 to 15 dB, no correction is required if background noise is more than 15 dB lower than product noise, compliance to ISO 3744 cannot be claimed at frequencies where the difference is less than 6 dB. As it can be seen from the data in figure 8, the test room complies to this requirement starting from 125 Hz with a correction factor at specific frequencies, however the lowest valid frequency is 200 Hz (due to the dimension of the corner walls).

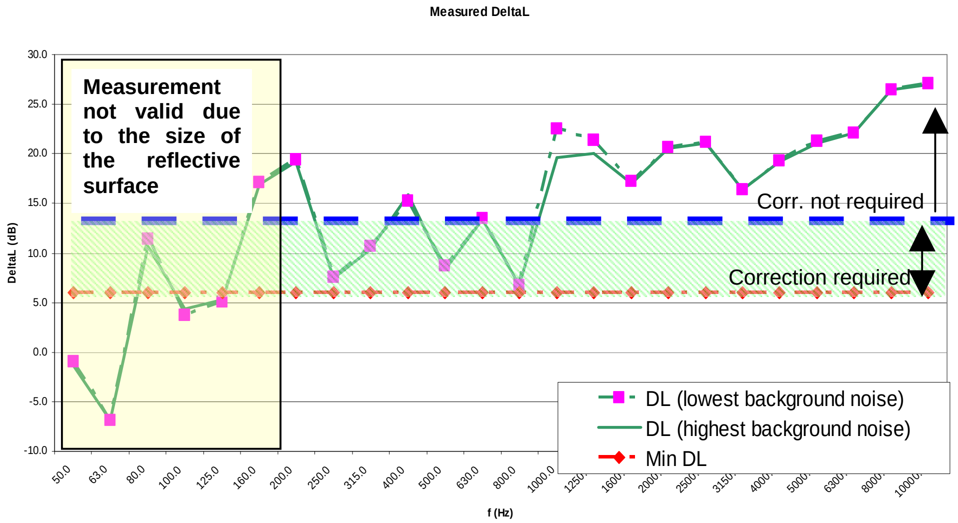

Figure 8. Compliance to background noise requirement prior to room improvements

However, since the data in Figure 8 indicates that a correction factor is required at a number of frequencies the compressor manufacturer decided that it was important to make room improvements in insure compliance in the event that the background level around the chamber increases or they make significant improvements to the compressors sound pressure levels. Modifications were made to the room to increase the transmission loss and widen the margin between their room performance and compliance according to ISO 3744. After the room modifications were made, additional measurements were used to compare the level of the quietest compressor to the new "worst case" background noise level. The results of the measurements taken after the room modifications were made are shown in Figure 9.

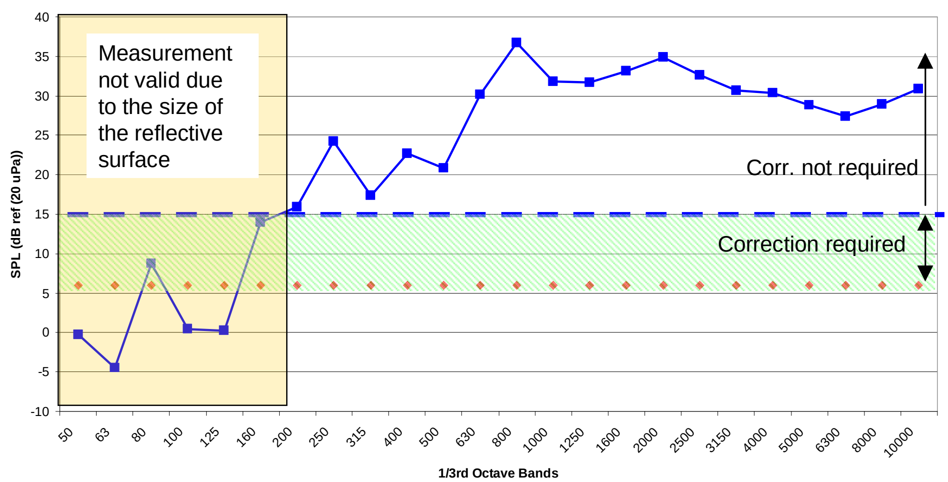

Figure 9. Compliance to background noise requirement after room NR improvements

4. CONCLUSIONS

Compliance to ISO 3745 is a target that many organizations shoot for to insure precise measurements of their product's sound power. Unfortunately compliance to ISO3745 demands very controlled and ideal conditions that are only achieved in extremely well designed and acoustically isolated labs. In many cases compliance to ISO 3744 will result in sound power estimates that are within the necessary precision levels. In this way the vast majority of industrial (i.e. Company internal) standards have requirements which align more with ISO 3744, which should be considered as a valid alternative for test standardization. Table 2 summarizes the expected level of precision, reported as the standard deviation of reproducibility for each of the two standards.

Standard deviation of reproducibility (σr)		
One-third-octave center frequencies	**ISO-3745**	
Hz	**Anechoic room dB**	**Hemi-anechoic room dB**
50 to 80	2	2
100 to 630	1	1.5
800 to 5,000	0.5	1
6,300 to 10,000	1	1.5
12,500 to 20,000	2	2
A-Weighted	0.5	0.5
One-third-octave center frequencies	**ISO-3744**	
Hz	**dB**	
50 to 80	5	
100 to 160	3	
200 to 315	2	
400 to 5,000	1.5	
63,00 to 10,000	2.5	
A-Weighted	1.5	

Table 2. Summary of the standard deviation of reproducibility of the sound power levels for ISO 3744 and ISO 3745 standards

ACKNOWLEDGEMENTS

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