Sound power level determinations at laboratory and field environments: An experimental comparison

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Abstract

Sound power level statement of equipment and machinery is increasingly relevant in terms of regulations and industrial competitiveness. When modelling the real world, Lw values constitute the input data for Lp predictions in diagnosis and planning of noise control strategies. Lw declaration has a major technical and economical impact, and accordingly, trying to keep the measurement uncertainties as low as possible, while balancing testing complexity, time consumption and costs is quite required. In the present work, a testing survey of real equipment emitting steady noise with different DI's and spectra is described. The applied methods had different grade of precision, ranging from ISO 3745 to ISO 3476, ISO 3741 based on Lp measurements, ISO 9614-2 based on Li, as well as a simplified proposals. The testing environments comprised an hemianechoic chamber, a reverberation chamber, a semi-reverberant normal room and an industrial hall. The calibration of a Reference Sound Source, RSS, BK 4204 [ISO 6926] used in the comparison tests is also described. A comparative analysis of results is made, considering the DI of sources, number of points, heights and environments, estimating the deviations of the different tests with respect to the reference precision method described in ISO 3745.

Keywords: noise emission, sound power, measuring standards
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1 Introduction

Sound power levels are adopted as the major parameters to describe the noise emission of machines and technical products. Sound power characterizes noise sources for specified operating conditions, and unlike field quantities such as sound pressure or sound pressure levels, it does not depend on the acoustic surroundings, neither on the location relative to the reception site, being an intrinsic property of the source.

The development of compatible products with the preservation of the environment, acquires day to day a growing importance in local and international competition, and sound power levels are used as key parameters for the acoustic characterization of machines and household appliances subjected to regulations. Even outside the regulated field, noise emission specified values are a matter of competition for consumers at the time of deciding in a market where the quietest products are related to a better quality. Besides, sound power levels of machines, are a key information for the acoustic characterization of existing or new industrial facilities allowing more realistic noise predictions as the input acoustic data becomes more realistic.

The experimental determination of sound power is currently based on the measurement of field quantities such as sound pressure or sound intensity. There are series of ISO standards that state different precision levels: ISO 3740 series, based on the sound pressure measurement, has three degrees of precision in different acoustic environments. The most precise methods, are complex and require an expensive infrastructure with very well controlled acoustic conditions, whereas the simplest methods can be applied in real environments provided they meet certain acoustic requirements, involve a smaller effort of execution but as a counterpart the achieved precision is smaller. ISO 9614 series are based on the measurement of sound intensity, and no expensive facilities are required in order to reach the highest stated precision. However, measurements are usually time consuming and complex, and require highly qualified personnel in order to get valid information.

In synthesis, there exists a wide spectrum of sound power level standardized methods, wherein the greater consumption of time and measurement complexity ensures a higher precision in the result. In reality, manufacturers and control agencies, are far from an ideal situation, test codes usually exist for a family of products, but they allow different options regarding the acoustic standards, claiming that comparable sound power levels result for the same grade of accuracy. However, extensive research in the past has shown that this is not true and that sound power levels depend on a number of experimental parameters that have to be thoroughly stated in order to get comparable measures. Accordingly, it is necessary to propose the use of uniform procedures with stated margins of error, thus allowing a fair competition of products based on homogenous assessment criteria.

Following a long term research programme [1], in the present work, the sound power levels of real sources determined by methods with varying degree of accuracy, different sampling
techniques and acoustic environments are analyzed. The work was oriented to obtain more information about possible systematic apartments from the “true values”, i.e. those obtained by the most precise technique under very well controlled laboratory conditions.

2 Measurements

2.1 Test environments

Four test environments with quite different acoustic behaviour were selected, ranging from a hemi-anechoic room with free field conditions over a reflecting plane to a reverberation chamber with a diffuse sound field.

In addition, two real environments were included, one of them with acoustic “hard” finishings and a few furniture, and the other one, an industrial hall with a large volume and a high density of dispersion objects.

The basic characteristics of the environments are described as follows.

2.1.1 E0

Hemi-anechoic chamber at the Acoustics Laboratory of INTI. It is a box-in-box like design built by the IAC Company, with an inner box mounted on resilient supports, structurally decoupled from an outer shell. The whole chamber, the air circulating equipment and silencers are located inside a large metallic shed.

The internal surfaces are covered with mineral wool filled wedges, except the floor that is a metal reflecting plane. The free internal volume is 315 m³, with a floor area (tip-to-tip of wedges) of 7 m x 10 m and 4.5 m high (up to the wedge tip). The inferior cut-off frequency is 75 Hz, and the background noise of 17 dBA is below the free field reference ISO threshold. The room for meets the requirements of ISO 3745 for the 1/3-octave bands from 100 Hz to 10 kHz.

2.1.2 E1

A 123 m³ reception area with ample glazed surfaces, smooth finishing walls/ceiling, and a hard floor. Measurements were made outside the working hours, when background noise levels were ≤ 55 dBA, which allowed suitable margins for all the sources under test. The environmental correction factor, K2, was determined by the comparison method using a B&K 4204 RSS. K2 values ranged from 8.9 dB to 4 dB for 1/3-octave bands from 100 Hz to 10 kHz, “A” compensated value, K2A, was 7.7 dB.

2.1.3 E2

An industrial hall of about 2500 m³, with plastered masonry walls, concrete slabs ceiling and a smoothed cement floor, with a high density of machinery and piping. Since it is a pilot experimental plant at INTI, it was possible to conduct the acoustic measurements for different operating conditions, getting an acceptable margin over the background noise levels for all the test sources. The background levels ranged from 87 dBA for full regime to 60 dBA when almost all machines have stopped. The environmental correction factor, K2, was obtained by
comparison using a source S0 (B&K 4204 RSS). K2 values ranged from 3 dB to 0.5 dB for 1/3-octave bands from 100 Hz to 10 kHz, and the “A” compensated value, K2A, was 1.5 dB.

2.1.4 E3

The reverberation chamber at the Acoustics Laboratory of INTI is a 0.40 m thick monolithic reinforced concrete structure, mounted on resilient supports, with 210 m$^3$ of internal volume. It has non-parallel opposite walls, a two-sided roof and fix diffusing elements. It qualifies ISO 3741 [3], the background noise level: 22 dBA and reverberation times with empty room, range from 9.5 s at 100 Hz up to 2 s in 8000 Hz 1/3 octave bands.

2.2 Sound sources

The noise sources used for testing were small to medium size electrical devices, with varied geometrical configurations and acoustic properties, namely the spectral composition and directivities. They were selected considering their availability during the long-term measuring campaign, to be portable with a standalone operation, fed from the mains supply without the need of special facilities (gas, water, air, etc.), to have short stabilization times and constant noise emission throughout the measurement times, to be self-standing on the floor and of simple assembly, among the main premises.

Six noise sources were selected. Their main characteristics are summarized in Table 1.

<table>
<thead>
<tr>
<th>Nº</th>
<th>Description</th>
<th>Reference Box [m]</th>
<th>$d_0$ [m]</th>
<th>DI [dB]</th>
<th>$L_{waA}$ [dB re 20μW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0</td>
<td>Reference Sound Source (RSS), B&amp;K type 4204, 220 V, 50 Hz</td>
<td>0,30 0,30 0,30</td>
<td>0,37</td>
<td>0,9</td>
<td>90,6</td>
</tr>
<tr>
<td>S1</td>
<td>Vacuum cleaner SHOP-VAC, model L 600, 220 V, 50 Hz, 800 W</td>
<td>0,35 0,35 0,55</td>
<td>0,60</td>
<td>3,4</td>
<td>95,6</td>
</tr>
<tr>
<td>S2</td>
<td>Circular saw RYOBI, model C/356-NA, 2100 rpm, 10,3 A.</td>
<td>0,48 0,27 0,70</td>
<td>0,75</td>
<td>5,6</td>
<td>99,7</td>
</tr>
<tr>
<td>S3</td>
<td>Radial fan York Ind. CYH8L, 2 HP motor, 2900 rpm</td>
<td>0,40 0,35 0,53</td>
<td>0,59</td>
<td>2,4</td>
<td>84,0</td>
</tr>
<tr>
<td>S4</td>
<td>Lawnmower BOSCH, model ARM 320, 3000 rpm, 950 W.</td>
<td>0,60 0,38 0,40</td>
<td>0,53</td>
<td>1,5</td>
<td>87,5</td>
</tr>
<tr>
<td>S5</td>
<td>Portable air heater no visible trademark), 3 HP motor, 220 V, 50 Hz.</td>
<td>0,55 0,35 1,42</td>
<td>1,46</td>
<td>6,2</td>
<td>77,1</td>
</tr>
</tbody>
</table>

where:

- $d_0$. Characteristic dimension [m]
- DI: directivity index, measured according to method, M1 described in Table 2, [dB].
- $L_{waA}$: A-weighted Lw obtained from 1/3 octave bands by method M0, Table 2, [dB re 20μW].

2.3 Measurement methods

A synthesis of the measurement methods is given in Table 2.
### Table 2: Measurement methods for determining Lw

<table>
<thead>
<tr>
<th>No</th>
<th>Method</th>
<th>Accuracy grade</th>
<th>Measured quantity</th>
<th>Measurement surface</th>
<th>SPL sampling</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>ISO 3745 [2]</td>
<td>1</td>
<td>Lp</td>
<td>Hemisphere</td>
<td>Automatic scanning</td>
<td>E0</td>
</tr>
<tr>
<td>M1</td>
<td>ISO 3745 [2]</td>
<td>1</td>
<td>Lp</td>
<td>Hemisphere</td>
<td>Fix points</td>
<td>E0</td>
</tr>
<tr>
<td>M2</td>
<td>ISO 3744 [4]</td>
<td>2</td>
<td>Lp</td>
<td>Hemisphere</td>
<td>Fix points</td>
<td>E0</td>
</tr>
<tr>
<td>M3</td>
<td>ISO 3746 [5]</td>
<td>3</td>
<td>Lp</td>
<td>Hemisphere</td>
<td>Fix points</td>
<td>E0</td>
</tr>
<tr>
<td>M4</td>
<td>ISO 3746 [5]</td>
<td>3</td>
<td>Lp</td>
<td>Hemisphere</td>
<td>Fix points</td>
<td>E0</td>
</tr>
<tr>
<td>M5</td>
<td>ISO 3744 [4]</td>
<td>2</td>
<td>Lp</td>
<td>Parallelepiped</td>
<td>Fix points</td>
<td>E0</td>
</tr>
<tr>
<td>M6</td>
<td>No standard</td>
<td>3</td>
<td>Lp</td>
<td>Parallelepiped</td>
<td>Fix points</td>
<td>E0</td>
</tr>
<tr>
<td>M8</td>
<td>ISO 3741 [3]</td>
<td>1</td>
<td>Lp</td>
<td>-</td>
<td>Automatic scanning</td>
<td>E0</td>
</tr>
</tbody>
</table>

In E0 (hemianechoic room) all methods from grade 1 to grade 3 were applied. In E1 and E2, two grade 3 methods: M3 and M4 based on ISO 3746 guidelines and a non-standardized proposal, M6, and the grade 2 intensity based method, M7, were carried out. In E3 (reverberation chamber), M7 and M8 were applied. It is worth mentioning that the intensity based method M7, could be applied in all the testing environments.

### 2.4 Measurement performance

#### 2.4.1 Method M0 in environment E0 for determining the reference values

The determination of sound power levels is performed in a free field over a reflecting plane at the hemianechoic chamber, E0, following the guidelines of ISO 3745.

SPLs were scanned automatically on a 2 m radius hemisphere centred at the geometrical centre of the sources projected on the reflecting plane, following a spiral path. Accordingly, the microphone oriented towards the source normal to the measuring surface, traverses a meridional path of quarter circle, covering the polar angles from the horizontal plane up to the vertical with a constant velocity of 3 mm/s projected on the vertical axis. Meanwhile, the sound source, mounted on a revolving platform flush to the floor, rotates at 0.75 rpm around its transverse axis, covering the azimuth angles with a uniform speed. From the combination of both movements, a spiral path on the hemisphere is described in about 11 min.

In Figure 1, the calibration setup of the B&K 4204 RSS is shown. 1/3-octave band L_w,s, ranging from 100 Hz to 10 kHz obtained at INTI are given graphically. PTB results obtained in previous
years are also included, showing the high long-term stability of the RSS, as well as a good correspondence between the measuring methods.

Figure 1: Calibration of RSS B&K type 4204, spiral path

The following instruments are used: microphone B&K 4133, preamplifier B&K 2637, sound analyzer B&K 2145. The microphone boom is held by a 0.5 mm steel wire wound onto a variable diameter steel shaft, moved by a BAUER regulator speed controlled motor.

Sound power levels, $L_w$, of the all testing sources were determined in a similar way, mounting one at a time on the revolving platform. Machines worked continuously for about 15 min before and after each measurement in order to check the stability of the emitted SPLs.

Figure 2: Sources F1 (Vacuum cleaner) and F4 (Lawnmower) during testing

Three replicates of each test were conducted in different days, in order to check the repeatability uncertainty, giving SDs < 0.15 dB for the whole frequency range, except for 100 Hz 1/3-octave band that raised to 0.30 dB. In Table 1, the averaged A-weighted sound power levels for the tested equipment are given.
2.4.2 Performed measurements

The applied methods are summarized in Table 3.

**Table 3: Description of the methods**

<table>
<thead>
<tr>
<th>Nº</th>
<th>Method</th>
<th>Q</th>
<th>Sm</th>
<th>r [m]</th>
<th>d [m]</th>
<th>Nº points</th>
<th>Nº heights</th>
<th>Description</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>ISO 3745</td>
<td>Lp</td>
<td>H</td>
<td>2 -</td>
<td>Path</td>
<td>Path</td>
<td>Spiral</td>
<td>E0</td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>ISO 3745</td>
<td>Lp</td>
<td>H</td>
<td>2 -</td>
<td>20</td>
<td>20</td>
<td>Points 1 to 20, Table E.2, Annex E (equivalent to 1 to 20 Table D.1, Annex D ISO 3745, 2003.)</td>
<td>E1</td>
<td>●</td>
</tr>
<tr>
<td>M2</td>
<td>ISO 3744</td>
<td>Lp</td>
<td>H</td>
<td>2 -</td>
<td>10</td>
<td>10</td>
<td>Points 1 to 10 Table B.1, Annex B, for all noise sources.</td>
<td>E2</td>
<td>●</td>
</tr>
<tr>
<td>M3</td>
<td>ISO 3746</td>
<td>Lp</td>
<td>H</td>
<td>2 -</td>
<td>4</td>
<td>2</td>
<td>Points 4, 5, 6 and 10 in Table B.1, Annex B, for broadband sources</td>
<td>E3</td>
<td>● ●</td>
</tr>
<tr>
<td>M4</td>
<td>ISO 3746</td>
<td>Lp</td>
<td>H</td>
<td>2 -</td>
<td>4</td>
<td>4</td>
<td>Points 10, 11, 12 and 20 in Table B.2, Annex B, for sources emitting predominant tones</td>
<td>E4</td>
<td>● ●</td>
</tr>
<tr>
<td>M5</td>
<td>ISO 3744</td>
<td>Lp</td>
<td>P</td>
<td>1 9</td>
<td>2</td>
<td>Reference box</td>
<td>E5</td>
<td>● ●</td>
<td></td>
</tr>
<tr>
<td>M6</td>
<td>-No standard-</td>
<td>Lp</td>
<td>P</td>
<td>1 1</td>
<td>4</td>
<td>1</td>
<td>Points 1, 2, 3, 4 of Method 5</td>
<td>E6</td>
<td>● ● ●</td>
</tr>
<tr>
<td>M7</td>
<td>ISO 9614-2</td>
<td>Li</td>
<td>P</td>
<td>1</td>
<td>Path</td>
<td>Path</td>
<td>-</td>
<td>E7</td>
<td>● ● ● ●</td>
</tr>
<tr>
<td>M8</td>
<td>ISO 3741</td>
<td>Lp</td>
<td>-</td>
<td>-</td>
<td>Path</td>
<td>Path</td>
<td>Comparison method using a B&amp;K 4204 RSS.</td>
<td>E8</td>
<td>●</td>
</tr>
</tbody>
</table>

Q: Measured quantity in dB; Sm: Measurement surface; H: Hemisphere; P: Parallelepiped; r: Radius [m]; d: Distance from the reference box [m]

Noise sources where carried to the different environments one at a time in order to perform the acoustic tests. For methods M3, M4 and M6, measurement positions were located on a hemisphere of 1 m radius for all cases, except for source S5, for which a 2 m radius was chosen due to its large height. In rooms E1 and E2, the environmental correction factors, $K_2$, were measured by comparison with S0 (RSS B&K 4204). In $E1K_{SI}=7.7$ dB was slightly above ISO 3746 limit, but methods M3 and M4 were applied anyway. The “A” weighted background noise levels met ISO 3746 requirements in all cases, but some 1/3 frequency bands in the lowest range were somewhat exceeded.

Method 7 follows ISO 9614-2 guidelines, based on the manual scanning of normal intensity levels on the five sides (segments) of a parallelepiped surrounding the sources. 1/3-octave bands from 100 Hz to 6300 Hz were measured and “A” weighted intensity levels calculated from the frequency bands. During manual scanning the sound intensity probe axis was kept as...
normal as possible to the measuring surface, while traversing equidistant paths with rounded turns at a constant speed. The scanning time for each segment was 20 s as a minimum.

At first, the measuring parallelepiped was located at distance of 0.50 m from the reference box. Field indicators were determined according to ISO 9614-2, \( F_{p1} \) (\( F_3 \) in ISO 9614-1) and \( F_{+/−} \) (\( F_3 − F_2 \)). The acoustic field was qualified according to the standard and consequently the measuring distances had to be reduced up to 0.15 m in some cases.

Finally, method M8 according to ISO 3741 by the comparison method using RSS S0 was performed in environment E3 (reverberation chamber).

![Sound Intensity probe](image)

Figure 3: (a) S2 (Circular saw) at E2, (b) S1 (Vacuum cleaner) at E2, (c) S1 at E3 during testing

For measurements in E0 two microphones B&K 4165 with preamplifiers B&K 2619, an intensity probe B&K 3520 with 12 mm spacer, sound analyzer B&K 2145 and a sound analyzer NORSONIC RTA 830-2 were used. For field testing the following instruments were used: sound level analyzer B&K 2260 with microphone B&K 4189, BZ 7206 software for SPL measurements, and for intensity measurements, an intensity probe B&K 3520 with 12 mm spacer and BZ 7205 software were used. The sound analyzer was mounted on a tripod in the fix microphone positions. For comparison tests a B&K 4204 RSS was used. In the reverberation chamber a microphone rotating boom B&K 3923 was used for automatic scanning of the sound field.

3 Analysis of results

Sound power levels obtained by method M0 were taken as the “true or reference” values \( L_{w0} \) of the noise sources. A-weighted levels \( L_{WA,0} \) will be analyzed in the present work. The systematic error of the different methods with respect to the “true” values are given by:

\[
\varepsilon = L_{WA,0} - L_{WA,n}
\]  

(1)
Error distribution for the different methods in environment E0 for all the measured sources, are given in Figure 4.

As could be expected, Grade 1 method M1, with 20 points/20 heights gave a mean error of 0.15 dB and the smallest SD: 0.15 dB. M5, based on ISO 3744 using a parallelepiped measuring surface with 9 points/2 heights, also shows a low SD: 0.18 dB, but the mean error is about 0.45 dB higher. Grade 2 M2 and Grade 3 M4, gave absolute mean errors below 0.05 dBA with SD: 0.4 dB. Grade 3 M4, gave a mean error of -0.13 dBA with SD: 0.4 dB The simplified method based on ISO 3746, M6, with 4 points/1 height gave the worst results, with a mean deviation of 1.6 dB and SD: 0.6 dB. Grade 2 M7, based on ISO 9614-2, gave a deviation of -0.03 dB and a lower SD: 0.4.

As shown in Figure 5 for environment E1, methods M3 and M4 have mean deviations of about -0.3 dB with SD=1 dB, while M7 has a mean deviation about 0.3 dB, with a SD= 0.5 dB. Method M6 has a mean error of 0.5 dB with the highest SD: 1.4 dB.
For E2, all methods have mean deviations that ranged from 0.1 dB to 0.4 dB above the reference, except M7 that mean deviation was cero. SDs from all the methods ranged about 0.8 dB, except for M7 that was about 0.5 dB. For environment E3, M8 gave a mean deviation of 0.8 dB with a SD: 0.1 dB, while M7 gave a mean deviation of 1.1 dB with SD: 0.4 dB.

A possible relation between DIs of the noise sources and the errors of the different methods was analyzed for environment E0. It was found that M3 and M6 had the highest dependence, $r$: 0.91, M8 had $r$: 0.38, and M7 had almost no correlation with $r$: 0.06.

4 Conclusions

Sound Power Levels of six small to medium size noise sources were determined by different methods and quite varied acoustic environments gave the expected results according to the standards. Each source was tested tracing a metrological chain ranging from the highest to the lowest degree of accuracy. The deviations from the “true” values, i.e. those obtained at the highest accuracy level at the laboratory, showed that the intensity based method, M7, described in ISO 9614-2 using manual scanning, could be applied in almost all field situations, giving the lowest dispersion of deviations in comparison with SPL based methods. The absolute mean deviations were $\leq 0.5$ dBA, except for the reverberation chamber, E3, were the field indicators did not met the standardized requirements. It is worth mentioning, that the manual scans on imaginary parallelepipeds around the sources, and only in few cases, the surfaces could be delimited by physical devices. Besides, it was found that the intensity based method, showed the lowest dependency on source directivities, which could mean that the errors due to the intensity probe positioning during the scans, are less significant than the SPL ones when measured at a few fix points around the source. The continuous sweeping of the sound field allows scanning at quite different heights. Consequently, ISO 9614-2 results a practical and reliable method specially in the case the field testing of noise sources, provided that the sound field qualifies according to the standard and the measurements are taken by well trained personnel.

References


