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LPSCAN – A PROJECT TO STANDARDIZE SOUND POWER DETERMINATION FROM SOUND PRESSURE SCANS

Fabian Heisterkamp[1*] **Volker Wittstock**[2] **Deborah Brosig**[2]
[1] Federal Institute for Occupational Safety and Health (BAuA), 44149 Dortmund, Germany
[2] Physikalisch-Technische Bundesanstalt, 38118 Braunschweig, Germany

ABSTRACT

Noise emissions from machinery are the main source of noise exposure for workers. To combat this risk at source, the European Machinery Directive requires the declaration of the main noise emission parameter, the sound power level. This quantity is determined according to 10 different EN ISO standards, requiring special laboratory environments or complex measurement techniques (reference sound sources, intensity probes, etc.). This high level of effort is considered to be a major reason why, despite legal requirements, noise data in instructions for 80% of machinery is unreliable or unavailable (NOMAD study). This project aims to reduce the measurement effort for machinery manufacturers, test houses and occupational health and safety personnel. To this end, existing methods, e.g., EN ISO 3744, that determine sound power from sound pressure measurements at discrete positions on the enveloping measurement surface around the machine shall be complemented by a new method based on manual sound pressure scans on the measurement surface. Ideally, these can be performed with a single microphone connected to a sound level meter. We present the results of first measurements on a model machine.

Keywords: *sound power, sound pressure scanning, basic sound power standards*

**Corresponding author*: heisterkamp.fabian@baua.bund.de

1. INTRODUCTION

Noise-induced hearing loss remains an important occupational safety issue. A significant contribution to reduce the noise hazard for workers can be made by purchasing “quiet machines”, which, in addition to suitable characteristics, are also characterized by the lowest possible noise emissions, in line with the “Sell and Buy Quiet” concept [1]. In order for companies to be able to choose quieter machines (“Buy Quiet”), manufacturers must provide comparable and reliable noise emission data (“Sell Quiet”).

However, a European market surveillance exercise, the so-called NOMAD (Noise Machinery Directive) survey revealed significant problems with the noise emission data provided in the instructions of machinery to be sold on the EU Single market [2]: 80 % of the noise emission declarations in more than 1500 investigated instructions did not meet the requirements of the EU Machinery Directive 2006/42/EC [3].

This rather poor compliance with legal requirements might – in part – be caused by the complicated basic noise emission standards that manufacturers have to apply to determine the noise emissions of their machines. Sec. 2 explains the application and as well the limitations of the existing standards in more detail, while Sec. 3 describes previous projects aimed at improving and simplifying the existing basic noise emission standards. Sec. 4 outlines the project LpScan, which aims to develop a new sound power standard, based on sound pressure scans instead of sound pressure level measurements at specified, fixed positions. Sec. 5 explains the methodology of this project, Sec. 6 presents the results of sound power measurements according to the existing ISO 3744 on a model machine and Sec. 7 concludes the paper with a summary and an outlook.

2. LIMITS OF EXISTING SOUND POWER STANDARDS

In accordance with the New Approach, many European Directives, such as the Machinery Directive [3], only define essential health and safety requirements, but not how they are to be achieved in detail/for each specific product. The EU-wide harmonization of product safety requirements is then achieved by means of harmonized standards, which are listed in the Official Journal of the European Union under the respective directive and the application of which is associated with a presumption of conformity (with regard to the requirements of the directive covered by the standard).

With regard to the noise emissions of machines, but also in general for other requirements of the Machinery Directive, a distinction is made between machine-specific standards, so-called C-standards, basic standards for specific hazards, etc. (B-standards) and basic standards (A-standards), defining principles, etc. (e.g. ISO 12100).

To determine the noise emission of a specific machine type, type-C standards define the applicable measurement methods by references to one or more B-standards, further measurement requirements, and the operating and mounting conditions.

There are many basic noise emission standards (B-standards) for determining the key noise emission quantity sound power level L_W. ISO 3740 [4] provides an overview of and information on when to use which B-standard/measurement method. The most important methods are the enveloping surface method (ISO 3744, ISO 3745 & ISO 3746), the reverberation room method (ISO 3741, ISO 3743-1, -2), the reference source method (ISO 3747) and the sound intensity method (ISO 9614, parts 1 to 3). The enveloping surface method, in particular the ISO 3744 and ISO 3746, makes relatively few demands on the measurement equipment, which is why the ISO 3744 method is the most widely used method. Most regulations, C-standards and product specifications refer to this accuracy grade 2 method.

However, ISO 3744 requires the determination of the environmental correction K_2 when used indoors outside of a hemi-anechoic test room and relies on fixed measurements positions. Both aspects may represent a challenge for machinery manufacturers, especially small- and medium-sized enterprises (SMEs), when determining the sound power level of their products on their own premises.

Measurements on larger machines and in particular on machines with a directed noise emission, e.g., from openings, vents, etc. require measurements on 21 or even more measurements positions (see Figure 7 showing the setup for model machine 1.)

This can increase the costs for the measurement equipment or when performed with a single sound level meter the measurement effort. Although sound intensity measurements according to ISO 9614-2 and ISO 9614-3 can be performed by intensity scans on the enveloping surface, using this method is no practical solution for SMEs. The measurement equipment is much more expensive than a sound level meter and the measurements require more expertise. Especially, since the current standards require the determination of partly unnecessary field indicators, which are not correlated to the accuracy of the determined L_W (see also Sec. 3) [5].

Thus, there is a need to develop an alternative method based on sound pressure level measurements that combines the low equipment costs of sound pressure level measurements and the reduction in measurement effort by scanning on the enveloping surface/measurement surface instead of measuring sound pressure on many fixed positions (see Sec. 4).

3. PREVIOUS PROJECTS AIMED AT IMPROVING BASIC NOISE EMISSION STANDARDS

In the course of its focus project “Practice-oriented simplification of noise emission measurement methods”, the Federal Institute for Occupational Safety and Health (BAuA) conducted several research projects aimed at a simplification of noise emission measurement of machines.

Project F 2438 “Simple approximate determination of the environmental correction” explored the feasibility of replacing expensive reference sound sources (RSS) with other small machines with sufficiently stable noise emission. The goal was to enable machinery manufacturers, in particular SMEs, to determine the environmental correction K_2 for the in-situ determination of the sound power level L_W themselves [6].

The local environmental correction K_3 for the in-situ determination of the emission pressure sound level requires even more effort. Project F 2495 “Determining the local environmental correction for the emission sound pressure level” investigated possibilities to simplify its determination and the effects of an amendment to ISO 11202:2010 [7].

Project F 2450 “Improving the practicability of the sound intensity method” was setup by BAuA and conducted by PTB in Braunschweig. It investigated potential simplifications to ISO 9614, parts 1 to 3 [5]. The project report contains drafts of a simplified ISO 9614, but these proposals have yet to be adopted in a revised version of the standard. Although the revision process has been started already, it will still take a while until the revision will be completed.

4. CURRENT PROJECT: LPSCAN – DETERMINATION OF SOUND POWER LEVEL BY SOUND PRESSURE SCANNING (F 2571)

The project F 2571 "Determination of sound power level by sound pressure scanning (LpScan)" is a joint research project of BAuA and PTB, the national metrology institute of Germany, setup in the framework of the BAuA focus project "Practice-oriented simplification of noise emission measurement methods". The aim of project "LpScan" is to develop a measurement method that determines the sound power level by scanning the sound pressure level around the machine [9]. Such a method has the advantage that the measurement can be carried out quickly using a single sound level meter. Compared to the sound intensity method (ISO 9614-2 and ISO 9614-3), which already works by scanning intensity on the enveloping surface, scanning with a single microphone connected to a sound level meter would offer great cost advantages (cost of measurement equipment). By moving the scans in the acoustic near-field of the machine, it might even be possible to perform the measurements without determining the background noise correction K_1 and the environmental correction K_2, making the method ideal for in-situ measurements on the premises of SMEs.
The project is planned for three years and the final result will be a draft for a standard to determine the sound power level of machines and other products from sound pressure scans on the enveloping surface, in openings of the encapsulation and in a few centimeters from the machine surface.

5. METHODOLOGY OF PROJECT LPSCAN

5.1 General

The research question is: Can the sound power of a machine be determined with sufficient accuracy and reproducibility by scanning the sound pressure level on an imaginary surface (called the measurement surface or enveloping surface) around the machine with a microphone, and is this a useful addition to existing standardized measurement methods?
Based on theoretically describable model radiators (e.g. monopole, dipole, etc.), the sound pressure scanning method is first analyzed at a typical measurement distance of 1 m. The deviations of the results obtained with this method from the known sound power of the model radiators are determined by varying the parameters such as enveloping surface shape, scanning speed, density of the scanning paths, shape of the paths, required stationarity of the sound field, level and distribution of the background noise level, orientation of the microphone or hand-held sound level meter. In addition to the results for sound pressure scanning, the results for discrete measurement point arrays are also used for comparison. The result of this work package is a basic understanding of the sound pressure scanning method at typical measurement distances and the most important parameters to be considered. At the same time, appropriate measurements will be performed to determine the sound power of model machines (see 5.3) using sound pressure scanning to verify the theoretical results.
Another application of sound pressure level scanning, which will be investigated in the project and developed into a measurement method, is the relocation of the scans in the near-field of the source. At distances of only a few centimeters to the surface of the machine, it may be possible to dispense with both the background noise correction K_1 and the correction for noise reflected in the measurement environment (environmental correction K_2).

5.2 Near-field scanning

In the case of near-field scanning, two methods can be distinguished:
In near-field full-surface scanning, the microphone is scanned over the entire surface of the machine to be tested at a distance of a few centimeters. It is also suitable for determining the sound power of individual components of linked systems.
Near-field partial surface scanning is based on the assumption that the sound power of the source is essentially radiated from certain spatially limited partial surfaces, so that the sound power can be determined only by scanning these areas. This method is also highly relevant in practice, since it can be used whenever machines are encapsulated for noise reduction, but openings in the encapsulation must be present for the machine to operate (e.g. in beverage filling machines).
In the context of near-field partial surface scanning, analytical calculations are conducted using synthetically generated sound pressure distributions that are strongly inhomogeneous on enveloping surfaces. These distributions are designed to model, for instance, openings in source enclosures. The study investigates the conditions under which it is feasible to determine the total sound power that passes through the enveloping surface by measuring solely at the most radiating partial surfaces. The validity of these

calculations is substantiated by measurements conducted on model machines.

5.3 Model machines

For this project, three model machines with variable “configurations” will be used to simulate measurements on real life machines under reproducible conditions. The machines are built from aluminum profiles and dampened aluminum sheets (see Figure 1 [7]).

Figure 1. Model machine 1 with a circular opening (Configuration I).

Three to four Brüel & Kjaer (Type 4204) aerodynamic reference sound sources (RSS) are placed in the model machines to ensure a sufficient, stable, reproducible and broadband noise emission. Each RSS has a sound power level $L_{WA} \approx 93$ dB. The configurations of openings in the model machines can be varied to allow the testing of different, but yet “challenging” configurations that have a directed, non-uniform noise emission in common.

5.3.1 Model machine 1

Model machine 1 has the following dimensions:
1,74 m×1,12 m×1,67 m (length × width × height).
The dimensions shall represent the dimensions of realistic machines, but yet have to be handled under laboratory conditions.

Figure 2 shows a sketch of the model machine 1 in the configuration with a circular opening that represents a small area dominating the noise emission on that side (configuration I).

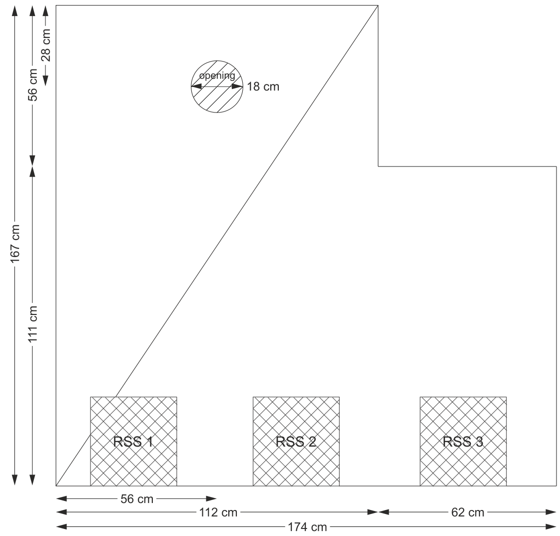

Figure 2. Sketch of model machine 1 with a circular opening (configuration I) [7].

The panel with the opening can be replaced with an open frame (configuration II (see Figure 3)) or a completely closed panel (configuration III).

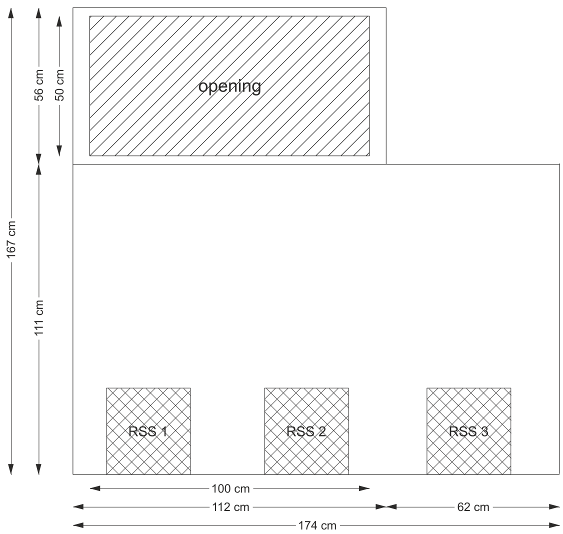

Figure 3. Sketch of model machine 1 with an open frame (configuration II) [7].

5.3.2 Model machine 2

Figure 4 shows a sketch of model machine 2 seen from the side. It has the following dimensions:
3,24 m×1,12 m×1,65 m (length × width × height).

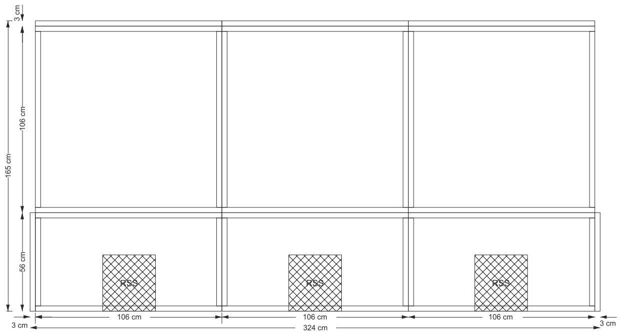

Figure 4. Sketch of model machine 2 (side view).

With openings at the ends, model machine II is designed to investigate partial-surface near-field scanning, where the goal is to determine the sound power level by scanning in these openings only.

5.3.3 Model machine 3

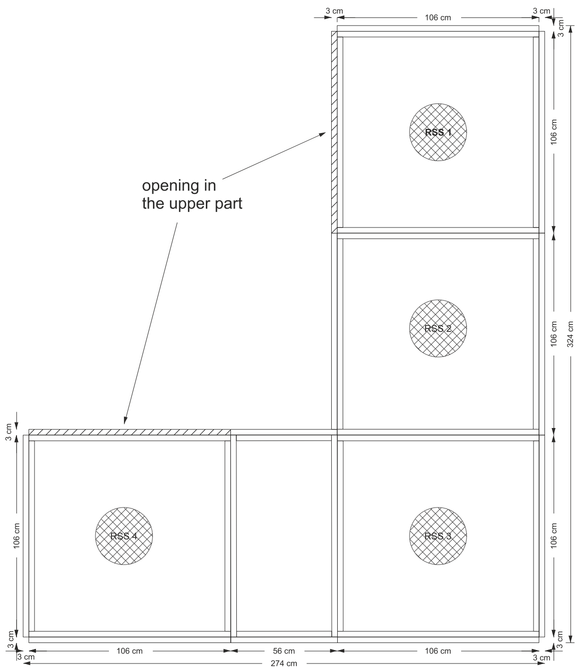

Figure 5. Sketch of model machine 3 (top view).

Figure 5 shows a sketch of the L-shaped model machine 3 seen from the top. Here, four RSS ensure a sufficiently high level of noise emission. The L-shape will be particularly demanding for full-surface near-field scanning, as noise emissions from the other opening might disturb the measurement, and maybe even when scanning at typical distances from the surface (d = 1 m).

5.4 Analysis of the results and comparative measurements

The findings from the calculations as well as the measurements on the model machines are then used to define a measurement method, which is subsequently tested through comparative measurements involving at least BAuA and PTB as participants. If feasible, additional cooperation partners should be sought to participate in these measurements, with the aim of determining the standard deviation of reproducibility of the measurement method.

5.5 Finalizing the report including a draft standard

The project will be concluded with a comprising report in English. As the key part of the report, the measurement method developed will be formalized as a draft standard. It is to be standardized as an EN ISO standard and will constitute a basic noise emission standard (B-standard) equivalent to ISO 3744. This basic standard for determining the sound power level by means of enveloping surface sound pressure scanning will also include criteria for the circumstances under which full-surface near-field scanning or partial-surface near-field scanning can be used while ensuring sufficient accuracy and reproducibility.

6. FIRST MEASUREMENTS ON MODEL MACHINE 1

We determine the sound power level of model machine 1 according to ISO 3744:2010 [10] using measurements at discrete positions on an enveloping surface/measurement surface. Due to the size and shape of model machine 1 a parallelepiped measurement surface with a distance d = 1 m from the reference box was chosen. According to ISO 3744, this meant that already 21 measurement positions were necessary (see Figure 6) – not taking account of possible non-uniform noise emission yet.
Figure 6 shows the setup for the sound power determination in the hemi-anechoic chamber. This test room is qualified from 63 Hz to 12,5 kHz according to ISO 3745.

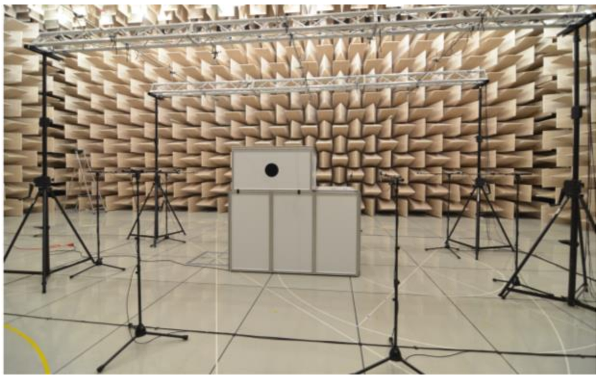

Figure 6. Model machine 1 and the setup according to ISO 3744 in the hemi-anechoic chamber at BAuA.

The measurements are conducted with 21 Brüel & Kjaer Type 4190 1/2-inch free-field microphones (IEC 61672 class 1) connected to a Brüel & Kjaer PULSE LAN-XI measurement system with 28 channels. This system is calibrated by an accredited external laboratory every two years. A system unavailable to most machinery manufacturers, especially SMEs.

However, even this high number of measurement positions is not sufficient to fully meet the requirements of ISO 3744 for configurations I and II of model machine 1, where sound pressure levels at the microphones near the circular opening and open frame, respectively, are higher. Here, 18 additional measurement positions are placed near the opening to ensure a proper sound power determination despite the directed emission of the source (see Figure 7).

Figure 7. Model machine 1 and 18 additional measurement positions according to ISO 3744 in the hemi-anechoic chamber at BAuA.

The sound power level L_W was calculated from the sound pressure level measurements at these 21 plus 18 measurement positions using the method described in Ref. [11]. Table 1 shows the sound power level for all three configurations of model machine 1. Note that the L_W of configuration III (closed) was determined from 21 measurement positions only.

Table 1. Sound power level of model machine 1 in different configurations, determined according to ISO 3744 [10].

	Conf. I Circ. open.	Conf. II Open. fr.	Conf. III Closed
L_W (dB)	88,8	93,0	87,4
L_{WA} (dB)	83,9	91,7	81,3

As expected, the sound power level of the configuration with the largest opening (configuration II, open frame) is the highest.

7. SUMMARY & OUTLOOK

We describe the details of Project LpScan. This project aims at developing a sound power standard based on (manual) sound pressure scanning. First results characterize the sound power level of model machine 1 using the existing enveloping surface method and demonstrate how much effort the established method according to ISO 3744 requires for such a machine (especially configurations I and II with a non-uniform noise emission).

As the main goal, the project will result in a new sound power standard (EN ISO) to be harmonized under the European Machinery Directive 2006/42/EC. This standard will support machinery manufacturers, in particular SMEs, to properly determine the sound power level of their products on their own premises with reduced effort. In turn, reliable noise emission data for machinery will improve market transparency regarding low noise machines. This enables employers to better protect their workers from noise by "Buying Quiet" when purchasing or hiring new machinery.

8. ACKNOWLEDGMENTS

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