Determination of Sound Power Level by Using a Microphone Array and Conventional Methods

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Abstract

Sound power is measured to make objective comparisons between the same type of products, but also because legislation requires it. To release a new product, it is often compulsory to certify it according to International Organization for Standardization (ISO) standards, and also with national and local regulations. Determining of sound power is not a straightforward process. Sound power can be determined through the measurement of sound pressure (series 3740 methods) or sound intensity (series 9614 methods). Selecting one of the above methods depends on the purpose of the test, as well as the available equipment, desired grade of accuracy, background noise level or the test environment. Nowadays the additional methods, such as microphone arrays are used to located of the noise source and determined of pressure sound level. But the results obtained with acoustic cameras cannot be, for now, used for legislative purposes (are not ISO compliant). In this work the differences in the determination of sound power level by using conventional ISO methods and microphone arrays are determined. The system composed of a loudspeaker and a fan were used as a sound source of the noise. Sound power levels according to ISO 3746 and ISO 9614-1 were determined and were compared with the developed method by using microphone arrays techniques.

Keywords: sound power level, ISO methods, microphone array, intensity probe

1. Introduction

Sound power quantity used in order to describe the noise emitted by sources is independent of the acoustic surroundings. The value of sound power is reproducible for any test conditions and is, therefore, an excellent indicator for comparing noise sources. Sound power measurement is employed in order to facilitate machinery noise reduction and to determine whether the operation of a machine is consistent with noise legislation and standards. Machines and equipment must be designed and manufactured in such a way that the risk of noise hazard is as low as possible and, additionally, in European Union the "Noise and machinery directive 2006/42/EC" requires that noise levels must be determined by measurement, and be declared in the product documentations [1]. The aim of the directive is that users and buyers must be able to assess and compare machines on all aspects of health and safety, including noise [2-6].

The three different qualities describe the sound: sound pressure level, sound intensity and sound power level. Sound power level can be calculated through sound pressure or sound intensity measurements. Sound power level is consistent, comparable, and more practical for noise control measures. There are various methods, having different accuracy levels, in different acoustic fields. Generally, the preferred method is the method in which sound pressure level is measured over an enveloping surface, surrounding the noise source hypothetically, and then sound power level is calculated by using surface averaged sound pressure level and measurement surface area. The selection between pressure and intensity measurements is based on numerous factors such as the acoustic nature of the environment, ease of application, access to measurement instruments, and speed of the experiment.

To determine the sound power level of machinery or equipment, based on the measurements of sound pressure, the two most important series of standards are ISO 3740 and ISO 11200 are used [6, 7]. The ISO 3740 series describes the methods of measuring noise emissions from machinery in terms of sound power level, both A-weighted and in frequency bands. The ISO 11200 series describes methods of measuring emission sound pressure levels in a controlled acoustical environment. The sound intensity methods for determining of sound power level are standardized in ISO 9614 methods [8]. These methods can be used in-situ in almost any acoustic environment. The sound intensity method is best suited for research and development, for engineering testing and is used for engineering measurements in the development of a new product, and also in-situ measurements.

Nowadays, because of the development of Industry 4.0, where automated processes are used, the system of data collection and transfer from any location should be used. Thanks to this many data analysis, procedures can be used to create shop floor schedules or prevention system in industry process [9, 10]. But many manufacturing situations have got dynamic nature, due to the movement of material. Dynamic processes are harder to analyze due to the change in mass and shape of the systems. This makes real-time analysis difficult. The development of new measured techniques like microphone array or vibrations detectors makes monitoring of these process is much easier and faster.

In this work the differences in the determination of sound power level by using conventional methods according to ISO 3746 and ISO 9614-1 and microphone arrays (acoustic camera) are determined. The system composed of a loudspeaker and a fan were used as a sound source of the noise. The calculated values of sound power level and standard uncertainty of the mean are compared and discussed.

2. Experimental method

The measurements were performed on the specially constructed test stand at the Institute of Power Energy in Lodz – Figure 1. The anechoic test chamber is cubic, approximately 350 m^3 in size and has walls that are acoustically treated with foam wedges providing a reflection-free environment. The system composed of a loudspeaker and a fan were used as a sound source of noise – Figure 1.

Figure 1. System of noise source composed from loudspeaker and fan, and measurement with sound analyser (on the left), intensity probe (in the centre) and acoustic camera (on the right) are being made

Three types of equipments were used in these studies:

1. sound analyzer as a sound meter (SVAN 958A with preamplifier and measurement microphone MK 255). The microphone was calibrated before commencing the acoustic test;
2. intensity probe with the configuration of microphones face to face and 12 mm solid cylindrical spacer separate, connected with analyzer and post-processing system (type 3545 with analyzer 2241). The probe was calibrated in sound intensity calibrator type 3541;
3. acoustic camera (Noise Inspector), with 40 MEMS microphones and HD camera and software which allow real-time sound imaging for quick results. The microphones were not calibrated before the measure because of due to the construction they do not require frequent calibration.

The first two measuring devices were used for testing the standard ISO methods (conventional). These methods, PN EN ISO 3746 and PN EN ISO 9614-1, specify a measuring the overall weighted sound pressure levels at prescribed microphone positions around the noise source. The A-weighted sound power level is calculated from these measured values. The minimum number of the key microphone positions over "box measurement surface" depends on dimensions of the noise source, measurement distance and also on the type of partial grids, dividing the measurement surface [11]. In this study, eight key microphone positions at 0.6 m distance were used in accordance, over the parallelepiped measuring surface (but for the acoustic camera because of its technical limitations, the distance of 1m was used). In each eight key microphone positions, the three measurements were done by using each measurement equipment. The measurement surface, enclosing the source under test was defined, as is seen in Figure 2.

The third equipment used in this study was an acoustic camera. Microphone array (beamforming) seem to be the most promising techniques to separate different sources. The beamforming technique starts from the microphone signals, perceived by some transducers fixed to a frame, whose geometry has to be properly designed, and reconstructs the sound field in each location within a pre-defined region of space.

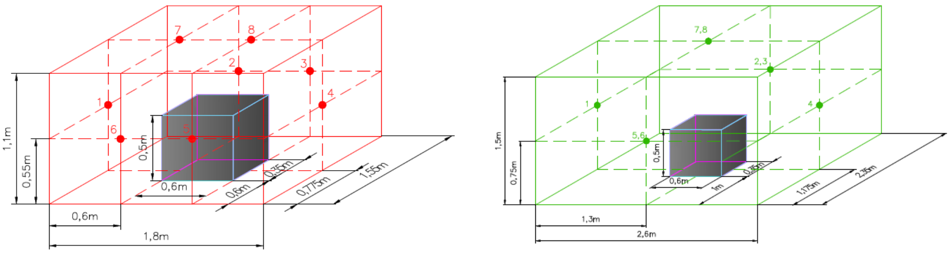

Figure 2. Scheme of measurement points for sound analyser and intensity probe (on the left) and for acoustic camera (on the right)

Literature gives many methods to process array measurements in order to identify sound sources. The oldest, but very simple, is the Delay & Sum Technique [12]. The "delay and sum" beamformer takes a set of the time difference of arrival which determine where the beamformer is steered and computes the outputs $s_B(t)$ as (1):

$$s_B(t) = \frac{1}{K}\sum_{m=1}^{K} s_m(t+\tau_{ml}) \tag{1}$$

where l is a reference microphone which can be chosen to be the closest microphone to the sound source so that all τ_{ml} are negative and the beamformer is causal. To steer the beamformer, one selects TDOAs (time difference of arrival) corresponding to a known source location. Noise from other directions will add incoherently, and decrease by a factor of K^{-1} relative to the source signal which adds up coherently, and the beamformed signal is clear [13].

The images from the acoustic camera were done in the same planes as in conventional methods. From each plane, in the strongest signal (red area – in maximum values) the 1/3 octave spectrum was calculated by the chosen algorithm, and thanks to that, the single global (for all plane) and local (the same points like used in conventional methods) values of sound pressure were calculated. Signal not processed by algorithm Delay & Sum image and processed by this algorithm from the acoustic camera is presented in Figure 3 and Figure 4.

3. Determination of sound power

The purpose of the tests was determining sound power level the source of noise, composed of two individual sound sources. The sound sources were placed on the floor. The setting the loudspeaker and fan simulated a machine as an object with a clear directional sound character, which in industry area is common. The average values sound pressure level in specific points determined according to ISO methods and for the acoustic camera in the measurement planes are presented in Table 2.

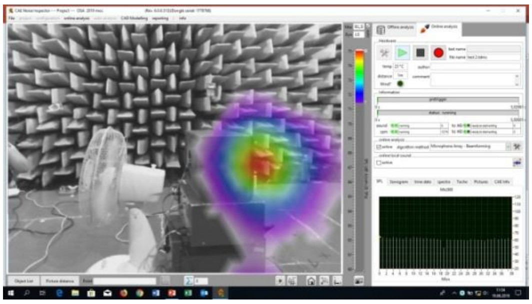

Figure 3. Non-processed image from acoustic camera for point 2 and 3

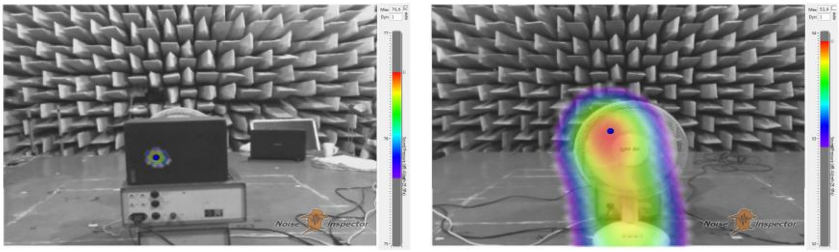

Figure 4. Calculated image by Delay and Sum algorithm
from acoustic camera for point 1 and 4

Sound analyzer SVAN 958 used in these studies, is treated as a standard method, because of this equipment is under metrological supervision. There are differences between the values of sound pressure level (SPL) obtained by different methods. It is seen from Table 1, that in point 1 the highest value of SPL is from SVAN 958 (83.9 dB), and the lowest from local signals of the acoustic camera (66.8 dB). Similar values of SPL are between obtained from SVAN958 (83.9 dB), intensity probe (80.7 dB) and global signal of acoustic camera (79.1 dB). Values obtained from local points of the acoustic camera (corresponding to measure points of conventional methods) are too lower and should not to be taken into account.

The main goal of this work was the determination of the sound power level. Sound power is the rate per unit time at which airborne sound energy is radiated by a source, and its unit is Watt [W]. The sound power levels L_w is defined as (2):

$$L_W = 10\log_{10}(\frac{W}{W_0}), \text{dB} \quad (2)$$

where the reference sound power W_0 is 1 pW.

Table 1. Average sound pressure in selected points got by using different methods

Measurement point	**Intensity probe** L_{pA}	**Sound analyser SVAN 958** L_{pA}	**Acoustic camera -** L_{pA} **in maximum (red area)**	**Acoustic camera -** L_{pA} **global**	**Acoustic camera -** L_{pA} **local**
1	80.7	83.9	76.7	79.1	66.8
2	68.7	67.4	58.8	61.4	53.5
3	66.1	60.2			48.7
4	66.3	60.0	53.9	57.3	52.8
5	66.9	63.2	61.2	63.7	50.5
6	70.6	69.5			58.3
7	70.9	71.0	63.8	67.2	63.8
8	67.0	64.3			55.0

Sound power can only be calculated or determined based upon either sound pressure measurement or sound intensity measurement. So, given the measurement surface according to Figure 2 for sound analyser and intensity probe and for the acoustic camera, also the environmental correction and measurement conditions the sound power were calculated for each method and additionally type A uncertainties were estimated. The type A uncertainty was calculated as the standard uncertainty of the mean due to sampling, according to point D.4.2.9 of standard ISO 3746:

$$u_{mean} = \frac{s}{\sqrt{N_M}} = \frac{1}{\sqrt{N_M}}\sqrt{\frac{1}{(N_M-1)}\sum_{j=1}^{N_M}\left(L'_{pi(ST)} - L'_{pav}\right)^2} \tag{3}$$

where:

N_M – number of microphone positions, L'_{pav} – means of measured values $L'_{\mathrm{pi(ST)}}$.

The result of these calculations is represented in Table 2.

Table 2. Sound power level and standard uncertainty of the mean got by use different methods

Parametr	**Intensity probe**	**Sound analyser SVAN 958**	**Acoustic camera in maximum (red area)**	**Acoustic camera - global**	**Acoustic camera - local**
Sound power L_{WA}, dB	83.3	84.1	83.8	85.8	72.7
Standard uncertainty of the mean, u_{mean}, dB	1.7	2.7	3.8	3.7	2.3

When we consider the values of sound power obtained from different methods it is clean that four results can be taken into account: from SVAN 958, intensity probe, the maximum signal of acoustic camera and global signal of acoustic camera, where differences around 2.5 dB seem acceptable. The sound power from local signals (corresponding to measure points of conventional methods) of the acoustic camera is too lower, so in the case of the acoustic camera do not use the same reference points (measuring) as in the conventional methods (ISO).

The second aspect of tested methods was determining of standard uncertainty of the mean. In our study, the standard uncertainty of the mean for sound power level is the lowest for intensity probe but the highest for the maximum signal of the acoustic camera. That may be related to the precision of place the selected point on the image from the acoustic camera, in which the 1/3 octave spectrum is calculated necessary to calculate sound pressure level in this point and finally to determine sound power level. Relationship between standard uncertainty of the mean on the values of sound power and apply measurement methods is presented in Figure 4. The value obtained by the acoustic camera seems too high and requires further study and analysis.

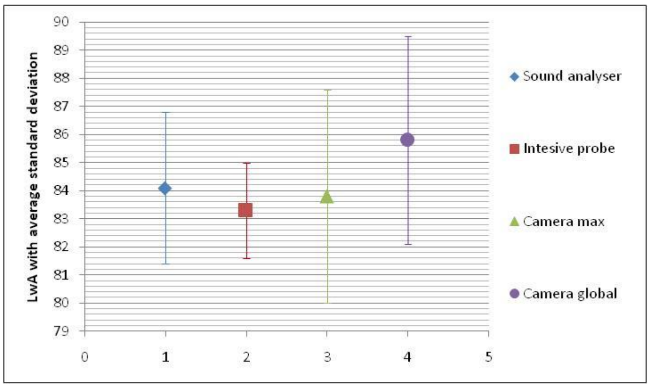

Figure 5. Relationship between standard uncertainty of the mean on the values of sound power and apply measurement methods

4. Conclusions

The three methods were used in these studies: sound analyzer as a sound meter, intensity probe with the analyzer and acoustic camera. Obtained results showed a quite good agreement between using methods. Difference between using the sound analyzer or intensity probe or acoustic camera depends on the characteristics of the source, the characteristics of the environment and distance of the measurement positions and the source. For the sound pressure methods, many restrictions have to be made for source characteristic and measurement environment in order to make the determination of uncertainty the sound power level within acceptable limits. Measurements of sound intensity are now fairly routinely made to determine the sound power of sources, machinery noise source identification and the transmission loss (sound reduction index) of structures. But acoustic camera seen nowadays as possibly the most progressive method might be also used to determine the sound power level. The benefits of this non-contact method can be used at a variety of machinery and equipment, even at greater distances. But for faster identification of faults or its prediction, it is necessary to create a database of samples with frequency characteristics of individual faults, which in the future may reduce costs and speed up this fault detection technology.

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