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INFLUENCE OF SOUND SOURCE LOCATION AND ABSORPTION ON DETERMINATION OF SOUND POWER LEVELS

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SUMMARY: Experimental research was performed to reveal detailed influence of two factors on measurement of sound power level according to ISO 3744:2010; location of a sound source in the room and reverberation time of the room. In industrial environment, large machines are often grounded near reflecting surfaces therefore some criteria from the standard can not be satisfied, or are only just satisfied. Additionally, most of the rooms can not satisfy required magnitude of the environmental correction so we selected to examine the influence of different acoustic absorption of the room. The main goal of the research was to determine the standard deviations of measured sound power levels as a measure of repeatability in different measurement conditions. Differences in the results of sound power level measurements were within the deviation value of 1 dB (A). The lowest measured value was obtained when source was located near the middle of the room and with the most covered room with absorbent material. Maximum value was measured when the source was located near the boundary surface of the room without absorption material.

Key words: *sound power level, noise, mechanical equipment, maintenance*

INTRODUCTION

Sound power level of the industrial product has today more significant influence on success on the market then it had in previous decades. Most of products are now shipped with the label that informs customers about product's sound power level but there are researchers claiming that machine labels should provide even more subjective information about the emitted noise *(Fernandez et al., 2008)*. Due to increased influence of sound power, equipment and methods for measurement of sound power level are continuously enhanced and reviewed to provide more reliable information *(Astrup, 1997, Cho and Mun, 2008, ISO 3744 : 1994, 2010, Marsh, 1981).*

Measuring the level of sound pressure was dominant method for resolving noise issues in previous time. Still, as unwanted noise issues had become more complex in recent times, so the measurement of the sound power took place more often. The sound power is a measure of acoustic energy emitted per time unit. Sound sources emit sound power and the sound pressure is a combined result of sound power and environment in which sound source is placed. The sound power can be considered as a cause and the sound pressure can be considered as an effect. One can hear the sound pressure emitted from the sound source with a given sound power.

Measurements of the sound power provide much more useful information then measurements of sound pressure alone. They enable

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comparison and selection of similar machines or devices coming from different manufacturers. Sound power measurements also enable a comparison of measured values with the recommended values of the acoustic emission for particular type of product *(Saarinen, 1999)*. Measurement results are also used to estimate level of noise generated by machines in any room or workplace in order to prevent hearing loss of workers due to the use of machinery *(Parmanen, 2007)*. In a scope of maintenance, the measurement of sound power level could be used to track and to estimate condition of the equipment *(Kolumbić et al., 2001)*.

The measuring method recommended in the standard ISO 3744 is the most frequently used in practice because of its simple procedure. However, the results of measurements of sound power level could be influenced by several factors such as:

- location of measurement (open or closed area);
- atmospheric conditions;
- geometry of test room;
- location of the sound source and the presence of reflective surfaces;
- the acoustic characteristics of the reflective surfaces;
- sound absorption of boundary surfaces in the test room;
- the level of residual noise;
- the type and calibration of measuring equipment;
- the position of source in the testing room;
- the size and shape of the measured surface;
- number and position of the microphones on the measuring surface;
- the duration of measurement;
- and some others less pronounced.

In this experimental paper we performed experimental research in purpose to reveal detailed influence of two factors on measurement of sound power level: location of a sound source in the room and acoustic absorption of the room.

Incentive to consider location of a sound source in the room as the first variable factor in our experiment came from the standard for determination of sound power levels - ISO 3744: 2010. Standard requires that the test room shall provide a measurement surface that lies inside a sound field that is essentially free of undesired sound reflections from the room boundaries or nearby objects (apart from the floor). Besides, the test environment shall be free from reflecting objects as far as it is practicable and the reflecting planes shall extend at least 0.5 m beyond the projection of the measurement surface on the planes. In industrial environment, large machines like tooling machines are often grounded near to reflecting surfaces so those measuring criteria are not satisfied, or are at the minimum distances required in the standard. Therefore, we considered several locations of a sound source in the room to find out what measuring results of the sound power levels could be expected in such cases and to compare results with those obtained in full conformity with the requirements of this International Standard.

The standard ISO 3744: 2010 also specifies procedures for determining the magnitude of the environmental correction, K_{2i}, in each frequency band i over the frequency range of interest, to account for deviations of the test environment from the ideal condition (hemi-anechoic room). Measurements in accordance with this International Standard are only valid where K_{2A} is less or equal to 4 dB (A), where index A denotes frequency A-weighting. Most of the rooms in manufacturing facilities can not satisfy this required magnitude of the environmental correction so we selected to examine the influence of different acoustic absorption of the room combined with the location of a sound source in the room in our set of experiments.

The main goal of the research was to determine the influence of the two parameters, which describe measurement conditions, on the deviations of measuring results. We expected noteworthy difference between measured values in relation to the parameters that were changed during the measurement - the position of sources in the room and room absorption.

Differences in the results of sound power levels measurement were within the values of 1 dB (A). The lowest measured value was obtained when the source was located near the middle of the room and with the highest absorption; that is with shortest reverberation time. Maximum value was obtained when the source was located near the boundary surface of the room with no additional absorption material in the room.

DESIGN OF THE EXPERIMENT

A method of accuracy grade 2 (engineering grade), in accordance with ISO 3744:2010 was applied to determine the sound power of the sound source. The requirements of applied method regarding environmental conditions and measurement equipment are summarized in Table 1.

Measuring was performed indoors, in the test room – classroom, which is 6.70 m wide, 9.11 m long and 3.33 m high. One corner of the test room is reduced by chimney; its dimensions are 0.90*0.95 m. Total volume of the classroom seizes 202.40 m^3 and total area 225.91 m^2. Additional space from indented window area is also calculated in the total volume of the classroom. The floor of the room was paved with wooden laminate and sidewalls were covered with the same laminate up to 1.20 m high. Furniture was removed from the test room (Fig. 1)

Table 1. The requirements of measuring sound power level according to engineering grade method

Tablica 1. Zahtjevi za mjerenje razina zvučne snage u skladu s metodom inženjerske klase točnosti

Parameter	Condition
Test environment	outdoors or indoors
Floor	hard surface with $\alpha \geq 0$
Environmental correction, K_{2A}	≤ 4 dB
Size of the noise source	unlimited size
Type of the noise source	all types
Difference between time-averaged sound pressure level with the noise source under test in operation and the background noise, measured and averaged over the microphone positions on the measurement surface, ΔL	≥ 6 dB at least ≥ 15 dB preferably
Background noise correction, K_1	≤ 1.3 dB
Difference between the highest and lowest levels on measurement surface	< 10 dB
Number of the microphone positions	≥ 9
The instrumentation system	IEC 61672-1:2002, class 1[10]
Filters	IEC 61260:1995, class 1[11]

Figure 1. The test room with equipment for the experiment

Slika 1. Ispitna prostorija s mjernom opremom za provedbu eksperimenta

Figure 2. The auxiliary framing and covering plates in the test room

Slika 2. Pomoćna nosiva konstrukcija i ploče apsorbirajućeg materijala u ispitnoj prostoriji

The influence of reflections and amount of absorbing material on the correction factor K_2 was considered in the first set of measurements. The amount of absorbing material in the test room was first statistical factor and it was changed for the three times during the experiments. Measurements of sound power level were performed for three different absorption conditions in the test room. One set of the experiments was performed without additional sound absorbing covering. It is marked with letter "N" in the label of particular experiment. Second set was measured with partial room covering, marked with "P". Measurements were performed with 36 m^2 of absorbing material in the room. Third set of experiments included the highly absorbed test room (marked with "D") with doubly covered, with 60 m^2 of absorbing material in the room. Plates of Stone wool type DP-9, with dimensions 120 * 20 * 8 cm, manufactured by Knauf Insulation / Tervol were used for the room covering. The boards were placed on the walls to each other, the spacing of about 8 cm, up to about 140 cm. To set plates in the upper zone of the room, auxiliary framing was used and angled relative to the ceiling so to cover as many frequencies in terms of absorption (Fig. 2).

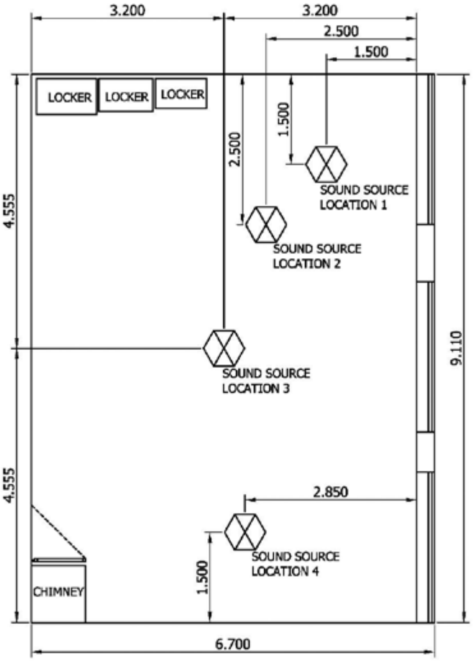

Figure 3. Sound source locations in the test room
Slika 3. Položaji izvora buke u ispitnoj prostoriji

As the second factor in the experiment we have considered influence of the sound source location in the test room on measured values of the sound pressure level. Four sound source locations were selected and labeled as shown in illustration (Fig. 3). The first location was selected close to two boundary surfaces – walls at the minimum distances required in the standard. The numerical mark "1" is used to denote the first location in the label of particular experiment. Translated from the first location for additional one meter in both horizontal directions was the second location, marked with "2". The third location of the sound source was in the horizontal medium of the test room, marked with "3". The fourth location was near the wall opposite from the first location and in the middle wall i.e. of the room width, marked with "4".

Correspondingly to two selected factors and their degrees of freedom an experimental plan was prepared for total of twelve (12) combinations. Each combination was marked with unique experiment label and measured three (3) times for each experiment, thus 36 measurements were performed overall (Table 2).

Table 2. Combinations of factors and experiment labels

Tablica 2. Kombinacije faktora i oznake eksperimenta

Absorption of test room	Sound source location	Experiment label	Number of measurements
N	1	N1	3
N	2	N2	3
N	3	N3	3
N	4	N4	3
P	1	P1	3
P	2	P2	3
P	3	P3	3
P	4	P4	3
D	1	D1	3
D	2	D2	3
D	3	D3	3
D	4	D4	3

The measurement system including microphones, cables and windscreen, meet the requirements of IEC 61672-1:2002, class 1; and the filters meet the requirements of IEC 61260:1995, class 1. Device used for measuring was modular precision sound analyzer type 2260 Investigator from Danish manufacturer Brüel&Kjaer. Analyzer received sound from the free field microphone type 4189 connected through 20 meter long extension cable. Results in frequency range from 50 Hz to 10 kHz were stored in the analyzer and processed with the included software BZ 7204 Building Acoustics. Unweighted equivalent sound pressure level was measured. The measurement time interval for all frequency bands was 30 s during the measurements with source in operation and during the measurements of residual noise.

For a sound source, omnidirectional dodecahedral speaker was selected. Omnidirectional dodecahedral speaker is commonly used for building acoustics measurements. During measurements, the speaker was placed on the floor of the test room with speaker's center at height 26 cm. Speaker emited pink noise, without audible discrete tones. The very structure of the speaker provides undirected radiation of the sound.

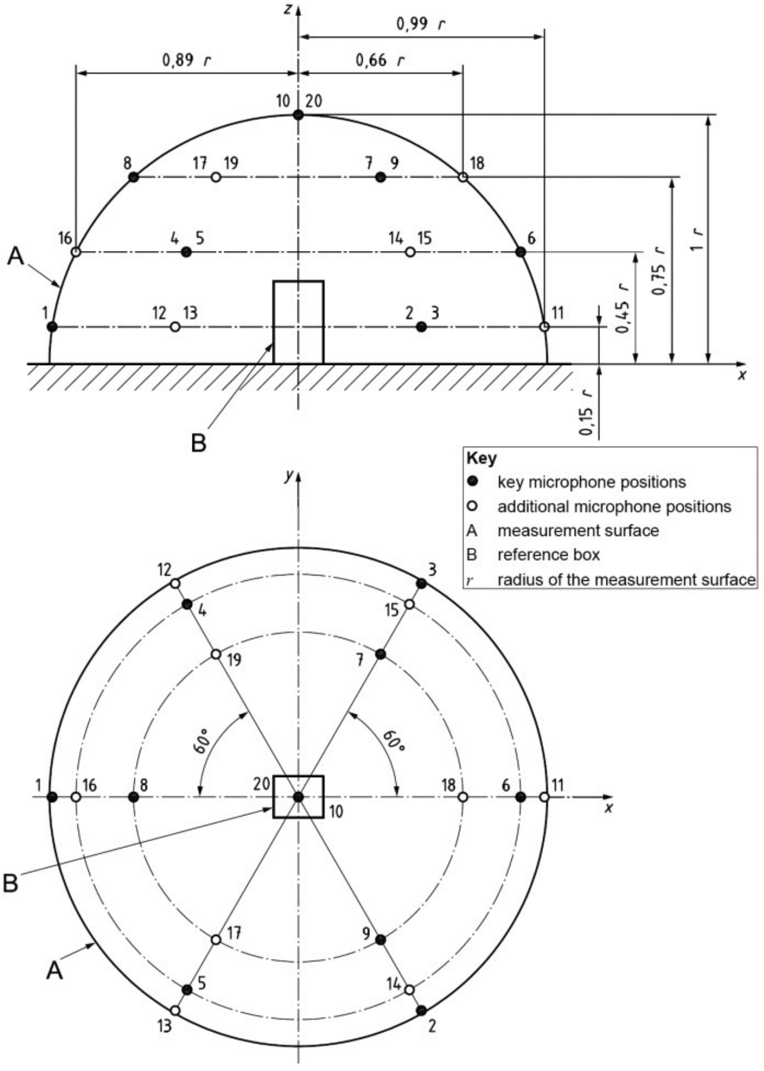

Figure 4. Microphone positions on the hemispherical measurement surface for a broadband noise source

Slika 4. Pozicije mikrofona na hemisfernoj mjernoj plohi za širokopojasni izvor zvuka

Prior to measurements, reference box was delineated. The reference box is a hypothetical surface defined by the smallest right parallelepiped that just encloses the source under test. Dimensions of reference box for selected source are 340 * 340 * 430 mm (W *L * H). The characteristic source dimension, d_O , used to determine the dimensions of the measurement surface is 492.6 mm. The measurement radius, r, shall be equal to or greater than twice the characteristic source dimension, d_O , not less than 1 m. The measurement surface used for our measurements was a hemisphere, with measurement radius, r = 1 m and measurement surface area S = 6.28 m^2.

Although standard allows that the number of microphone positions can be reduced from minimum 9 positions, if specific conditions are fulfilled, in this experiments sound pressure levels have been measured at ten (10) microphone positions as defined for the hemispherical measurement surface for a broadband noise source.

Since we have used a broadband noise source, which emits no audible discrete tones, 10 key microphone positions were selected, according to Fig. 4. The coordinates of the microphone positions are provided in Table 1. The origin of the coordinate system is located at the point of the vertical projection of the speaker's geometric centre on the floor.

Table 3. Microphone positions for a broadband noise source

Tablica 3. Koordinate položaja mikrofona za širokopojasni izvor zvuka

Microphone position	x/r	y/r	z/r
1	-0.99	0	0.15
2	0.50	-0.86	0.15
3	0.50	0.86	0.15
4	-0.45	0.77	0.45
5	-0.45	-0.77	0.45
6	0.89	0	0.45
7	0.33	0.57	0.75
8	-0.66	0	0.75
9	0.33	-0.57	0.75
10	0	0	1.00

The background noise correction (dB) is given by:

$$K_1 = -10 \log_{10} \left(1 - 10 \frac{\Delta L_p}{10} \right) \tag{1}$$

where:

ΔL_p - the difference between mean frequency-band or A-weighted time-averaged sound pressure level from the array of microphone positions over the measurement surface, with the noise source under test in operation and the mean frequency-band or A-weighted time-averaged sound pressure level of the background noise from the array of microphone positions over the measurement surface, in decibels. In this case measured $\Delta L_p > 15$ dB, so K_1 is assumed to be zero and no correction for background noise is applied.

The acoustic characteristics of the test room in which sound source was tested were calculated from measuring reverberation time and sound absorption. Environmental correction – constant K_2 (dB) is given by:

$$K_2 = 10 \log_{10} \left(1 + 4 \frac{S}{A} \right) \tag{2}$$

where:

A – sound absorption of the test room (m^2) determined on the basis of reverberation time measurement, as given by:

$$A = 0,16 \cdot \left(\frac{V}{T} \right) \tag{3}$$

V – the volume of the test room (m^3);

T – reverberation time in the room, (seconds).

The surface time-averaged sound pressure level, $\overline{L_p}$, is calculated by correcting the mean time-averaged sound pressure level, $\overline{L_{p(ST)}}$, for background noise (K_1) and for the influence of the test environment (K_2) using the equation:

$$L_p = \overline{L'_{p(ST)}} - K_1 - K_2 \tag{4}$$

The sound power level, L_W (in dB) for the meteorological conditions at the time and place of the test is calculated using equation:

$$L_W = \overline{L_p} + 10 \log_{10} \frac{S}{S_0} \tag{5}$$

where:

S is the area, in square metres, of the measurement surface; $S_0 = 1\ \text{m}^2$. Finaly the sound power level in the frequency band k can be calculated from measured values, Eq. (6).

$$L_{wk} = \left[10\log\left(\frac{1}{M}\sum_{m=1}^{M}10^{\frac{L_{pm}}{10}}\right)\right] - \left[10\log\left(1-10^{\frac{\overline{L}_{pm}-Lbckg}{10}}\right)\right] - \left[10\log\left(1+25\frac{T_{60'k}}{V}\right)\right] + \left[10\log\frac{S}{S_0}\right] \tag{6}$$

Measured value of sound pressure expressed in Eq. (6) for one frequency band depends on four terms. First term represents values of sound pressure, second term presents correction of background noise. Third term presents the correction value due to the influence of acoustic environment. Last term presents the influence of sound pressure drop with a distance, expressed with surface area ratio. This four articles present four uncorrelated sources of measurement uncertainty.

The A-weighted sound power level, L_{WA} in dB may be calculated using equation:

$$L_{WA} = 10\log_{10}\sum_{k=k_{min}}^{k_{max}}10^{0,1(L_{Wk}+C_k)} \tag{7}$$

where:

L_{Wk} - is the sound power level in the k-th one-third octave band, in decibels, k and C_k - are given in for octave bands, k_{min} and k_{max} - are the values of k corresponding, respectively, to the lowest and highest frequency bands of measurement.

RESULTS

Results of sound power levels determination under different measurement conditions (location of sound source and absorption of the test room) are shown in Fig. 5, Fig. 6, and in Table 5.

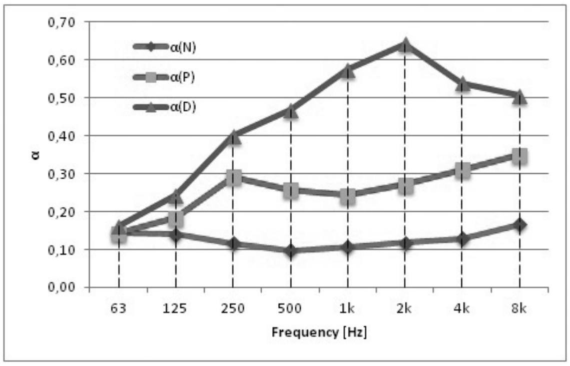

Figure 5. Mean sound absorption coefficient, α

Slika 5. Srednji koeficijent apsorpcije, α

Measured reverberation time varies in range from minimum of 0.22 seconds to maximum of 1.48 seconds. Averaged sound absorption coefficient, α, in octave band frequencies is shown in Fig. 5. It was calculated from sound absorption of the test room, A, which was determined from the measurement of reverberation time, according to equation (3) and total area of boundary surfaces S_V, using Eq. (8):

Table 4. Values of k and C_k for mid-band frequencies of octave bands

Tablica 4. Vrijednosti k i C_k za središnje frekvencije oktavnih pojasa

Mid-band frequency		
k	**Hz**	**C_k dB**
1	63	–26.2a
2	125	–16.1
3	250	–8.6
4	500	–3.2
5	1 000	0.0
6	2 000	1.2
7	4 000	1.0
8	8 000	–1.1

[a] This value of C_k given for use only where the test environment and instrumentation are satisfactory for use at the frequencies concerned.

$$\alpha = \frac{A}{S_V} \qquad (1) \quad (8)$$

Values of averaged sound absorption coefficient in the test room without additional sound-absorbing covering (first set of experiments) ranged from 0.10 to 0.17. In the test room with partial room covering (second set of experiments) values ranged between 0.14 and 0.35; while with doubly covered 60% of the room (third set of experiments) averaged values of sound absorption coefficient were in range from 0.16 to 0.64. It is evident that the acoustic characteristic of the room differs considerably between the first and the second set of the experiments, but does not differ significant between the second and the third set of experiments. Less pronounced difference at lower frequency range is expected due to porous absorption material used for covering.

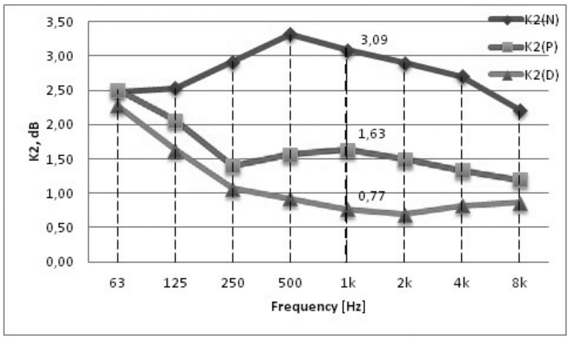

Figure 6. Values of environmental correction, K_2
Slika 6. Vrijednosti korekcije zbog uvjeta okoliša, K_2

Values of environmental correction factor for three different environmental conditions are presented in Fig. 6. The influence of reflected sound on calculation of the sound power level was quantified with the value of environmental correction K_2.

Value of K_{2A}, was calculated according to standard. Measured reverberation time at frequency range around 1 kHz (marked in Fig. 6) was used for calculation. The requirement of the engineering method ($K_{2A} \leq 4$ dB) was satisfied in all three sets of experiments. Frequency dependent values of K_2 ranged from 3.32 to 0.69 dB.

Table 5 presents determined sound power levels for octave bands in every particular measurement namely in every experiment as described in the experiment plan (Table 2). It also presents total linear sound power levels and total A-weighted sound power levels in last two columns. Last two rows of the table contain averaged values and standard deviations for every respected column.

DISCUSSION

In order to determine whether the measured results are significantly affected by position of source in the test room and test room absorption characteristics, they were statistically analyzed. Standard deviation of mean values and variances were determined for different combinations of influence factors.

By measurement of reverberation time in the exam room with a different degree of absorption of the room, expected results were achieved. By increasing the amount of absorption material in the room, reverberation time has shortened (longest was at intermediate frequencies from 250 Hz to 2 kHz) and the coefficient of absorption increased, except around frequency range 63 Hz. The reason for such result lies in the properties of dissipative absorption with negligible absorption coefficient at low frequencies and long reverberation time. Consequently, the absorption coefficient in frequency range around 63 Hz practically stayed constant during experiments.

All measurements were performed over the hemispherical measurement surface with the same radius $r = 1$ m, whose surfaces is 6.28 m^2. Therefore, the value of the environmental correction K_2, which was determined on the base on room absorption, depends solely on the coefficient of absorption. Values of K_{2A} were less than 4 dB for all cases of the absorption. This satisfies the criterion given by the standard for acoustic adequacy of test environment. Environmental correction values do not exceed a value of 3.5 dB in any frequency range, when measured in a room without absorption materials. Environmental correction values are lower than 1 dB at frequencies above 250 Hz for measurements in a room with 60 m^2 of absorption material.

Table 5. Sound power levels

Tablica 5. Razine zvučne snage

Measur.	**Exper. label**	L_W **(125 Hz) [dB]**	L_W **(250 Hz) [dB]**	L_W **(500 Hz) [dB]**	L_W **(1 kHz) [dB]**	L_W **(2 kHz) [dB]**	L_W **(4 kHz) [dB]**	L_W **(8 kHz) [dB]**	L_W **[dB]**	L_{WA} **[dB]**
1	N1	100.84	106.32	100.63	96.44	97.34	92.99	90.62	109.00	104.26
2	N1	100.79	106.34	100.67	96.44	97.35	93.00	90.61	109.02	104.28
3	N1	100.80	106.37	100.69	96.41	97.40	92.99	90.62	109.04	104.30
4	N2	100.37	105.90	100.19	96.10	97.14	92.63	90.32	108.59	103.92
5	N2	100.39	105.90	100.14	96.13	97.12	92.61	90.34	108.59	103.91
6	N2	100.33	105.86	100.16	96.14	97.11	92.68	90.42	108.57	103.91
7	N3	101.18	105.99	100.22	96.10	97.06	92.51	90.01	108.77	103.92
8	N3	101.14	106.01	100.24	96.12	97.06	92.50	90.01	108.77	103.92
9	N3	101.14	106.04	100.25	96.09	97.07	92.50	90.01	108.79	103.93
10	N4	101.18	106.33	100.81	96.30	97.16	92.71	90.26	109.06	104.20
11	N4	101.05	106.36	100.84	96.30	97.19	92.70	90.27	109.06	104.22
12	N4	101.12	106.29	100.84	96.29	97.19	92.68	90.28	109.03	104.20
13	P1	100.61	106.39	99.87	95.72	96.23	92.56	90.21	108.78	103.67
14	P1	100.53	106.43	99.84	95.69	96.24	92.54	90.20	108.79	103.67
15	P1	100.46	106.40	99.88	95.69	96.24	92.54	90.19	108.76	103.67
16	P2	100.32	106.04	99.83	95.58	96.34	92.63	90.24	108.53	103.58
17	P2	100.26	106.05	99.77	95.61	96.34	92.59	90.26	108.52	103.58
18	P2	100.26	106.09	99.78	95.63	96.37	92.61	90.27	108.55	103.60
19	P3	100.77	106.05	99.83	95.53	96.26	92.63	90.16	108.60	103.56
20	P3	100.92	106.06	99.72	95.49	96.21	92.63	90.16	108.62	103.53
21	P3	100.97	106.13	99.77	95.48	96.23	92.63	90.14	108.67	103.55
22	P4	100.74	106.01	99.48	95.51	96.34	92.54	90.21	108.53	103.49
23	P4	100.68	106.02	99.52	95.54	96.37	92.48	90.24	108.54	103.51
24	P4	100.77	106.07	99.54	95.53	96.36	92.53	90.22	108.58	103.53
25	D1	100.45	106.24	100.00	96.12	96.47	92.44	89.89	108.72	103.76
26	D1	100.41	106.20	100.06	96.13	96.52	92.44	89.90	108.70	103.78
27	D1	100.43	106.19	100.01	96.10	96.50	92.47	89.88	108.69	103.76
28	D2	100.36	105.91	99.85	95.56	96.15	92.68	90.24	108.46	103.51
29	D2	100.39	105.87	99.81	95.57	96.14	92.68	90.22	108.44	103.49
30	D2	100.40	105.82	99.80	95.57	96.14	92.66	90.22	108.41	103.48
31	D3	100.87	105.90	99.80	95.71	96.39	92.87	90.32	108.56	103.61
32	D3	101.00	105.89	99.81	95.63	96.40	92.87	90.30	108.57	103.60
33	D3	101.04	105.80	99.80	95.66	96.42	92.83	90.30	108.53	103.59
34	D4	100.92	106.25	99.80	95.95	96.69	93.08	90.69	108.80	103.85
35	D4	100.85	106.21	99.79	95.94	96.67	93.09	90.69	108.77	103.83
36	D4	100.94	106.21	99.73	95.93	96.65	93.11	90.67	108.77	103.82
x□		100.71	106.10944	100.02	95.88	96.63	92.68	90.27	108.70	103.78
S		0.30	0.19	0.38	0.32	0.42	0.19	0.21	0.19	0.26

Accuracy of sound power levels increases with decreasing the influence of reverberant component of room and the influence of background noise (Fig. 7). The range of measured values of A-weighted sound power levels is from 103.48 dB (A) to 104.30 dB (A).

The sound power of the source was constant during the performance of all measurements. It was found that the measured sound power level is highest in cases without absorption material in the test room - the smallest absorption of the room, in all positions of source in the room. In this case, the highest deviation of results was observed (the biggest difference between the highest and lowest measured values). Such values are expected due to the increasing influence of reverberant sound field, which is higher as the source (and measuring microphones) closer to the boundary surface of the room. In the case of partially covered room were determined, on the average, the lowest value of the measured sound power levels, and minimum considerable deviation of results. The lowest measured value of sound power level was observed in the case of a doubly covered room with the sound source positioned in location 2, specifically in experiment labeled D2. Such values are expected due to lower impact of reverberant sound field, due to increased absorption at the boundary surfaces of the room and the removal of the microphone from the boundary surfaces of the room.

Regarding the position of the source, it was found that the lowest measured level was obtained, when the source was located near the middle of the room (positions 2 and 3). Standard deviation of results in these cases was the lowest because of lower reverberant sound field at the position of the microphone away from the boundary surfaces the room. As expected, the highest measured values of sound power level were obtained in cases where the source was placed at the corners of the room - position 1, regardless of the absorption of the room. The exception to this rule is partially lined room and position 4, when the lowest level was measured and in relation to other positions in partially covered room, and in relation to other cases of lining boundary surfaces of the room with absorbent material.

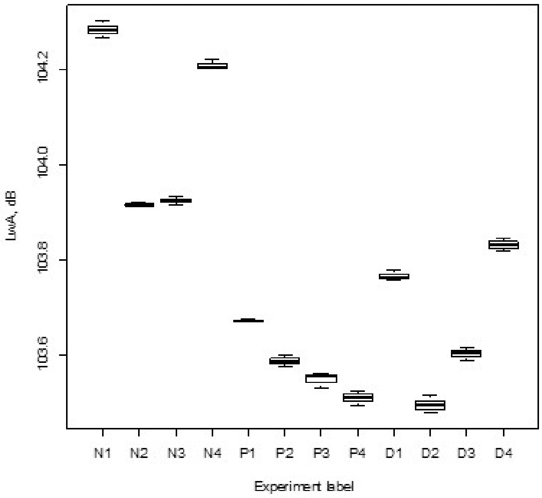

Figure 7. Boxplot diagram of measured sound power levels

Slika 7. Boxplot dijagram izmjerenih razina zvučne snage

With the purpose of exhaustive understanding of the effect of considered factors on the sound power levels, we performed a factorial analysis of variance (ANOVA) in R language (2011). ANOVA of experiment factors is presented in Table 6. The abbreviations used for factors are: ATR – Absorption of Test Room; SSL – Sound Source Location.

Table 6. ANOVA of experiment factors

Tablica 6. ANOVA razmatranih faktora u eksperimentu

Factors	Degrees of freedom	Sum of squares	Mean square	F value	Pr(>F)
ATR	2	1.7169	0.8585	4903.1	<2e-16
SSL	3	0.3760	0.1253	715.8	<2e-16
ATR:SSL	6	0.2048	0.0341	195.0	<2e-16
Residuals	24	0.0042	0.0002		

The ANOVA calculation confirmed that the absorption of test room is the most influential factor on the sound power level. The analysis also proved influence of sound source location and confirmed influence of combined interaction of two factors. ANOVA significance of influence is determined when compared to the critical value of Fischer's distribution with the probability of 0.95 and respective degrees of freedom (2; 24). However, such significance should be carefully considered in range of mean squares and range of overall results for sound power levels.

CONCLUSIONS

Considering the location of sound source in the room and absorption of the room, it can be concluded that sound power level measured with the source placed in the middle of the room i.e. away from the boundary surface and when the room is doubly lined with absorbent material are expected to be underestimated. Similar conditions are achieved in the semi-anechoic chamber, where measurements of sound power level with accuracy of class 1 (precision method), are carried out. In such acoustic environment the minimum impact of reverberant sound field due to reflections from the boundary surfaces of the room is expected.

As it is demonstrated, deviations of determined sound power levels of the same source measured in a closed room, if room just meets the criteria for environmental correction, in which case $K_{2A} \approx 4$ dB, are less than 1 dB compared to measurements performed in a room with $K_{2A} << 4$ dB.

If deviation of sound pressure levels on virtual plane are less then 1dB, when measured in acoustic environment with $K_{2A} \approx 4$ dB, then results of sound power level are statistically similar to results, when measured in rooms with $K_{2A} << 4$ dB

Results of measured sound power level differ if the noise source is located near the boundary surfaces of the room (in front of a wall or in corner), or if it is located at the middle of the room. The deviation due to source location was in our case less than 1 dB. Determination of sound power levels of machinery or equipment in order to determine either condition for maintenance, to determine the acoustic modeling for the reduction of noise or other purposes can be carried out with satisfactory accuracy in a room that just meets the criteria for environmental correction which is defined in ISO 3744. Measurements can be performed without the need for relocation of fixed or based sources, which are located near the boundary surfaces of the room. In such cases it is not necessary to invest in improving the acoustic properties of rooms improving the absorption, or relocation of machines located near the boundary surfaces of the room.

Further analysis of the influence of measuring conditions on the accuracy of sound power level determination is anticipated. Under the conditions of measurement would be appropriate to consider the background noise level, different types of measuring devices, the number of measurements on the measuring surface, the type of measuring surface and noise characteristics.

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UTJECAJ POLOŽAJA IZVORA ZVUKA I APSORPCIJE NA UTVRĐIVANJE RAZINE ZVUČNE SNAGE

SAŽETAK: Provedeno je eksperimentalno istraživanje s ciljem detaljnog utvrđivanja utjecaja dva faktora na izmjerene razine zvučne snage u skladu s postupkom iz norme HRN EN ISO 3744:2011 - položaj izvora zvuka u prostoriji i vrijeme odjeka prostorije. U industrijskom okolišu veliki strojevi često su smješteni u blizini reflektirajućih ploha i zbog toga neki kriteriji iz norme ne mogu biti zadovoljeni ili mogu biti samo djelomično zadovoljeni. Dodatno, većina radnih prostorija (proizvodnih hala, prvenstveno) ne zadovoljava zahtjev norme u pogledu iznosa korekcije zbog uvjeta okoliša. Utjecaj prostorije iskazuje se putem iznosa korekcije zbog uvjeta okoliša te su kao drugi utjecajni faktor odabrani za ispitivanje utjecaji različite akustičke apsorpcije prostorije. Glavni cilj istraživanja bio je utvrđivanje standardnih odstupanja izmjerenih razina zvučne snage kao mjere ponovljivosti pri različitim uvjetima mjerenja. Razlike u rezultatima razine zvučne snage bili su unutar odstupanja od ±1 dB(A). Najniže izmjerene vrijednosti utvrđene su kada je izvor bio postavljen u blizini horizontalne sredine prostorije i uz potpuno obložene zidove prostorije apsorpcijskim materijalom. Najviše vrijednosti utvrđene su kada je izvor bio postavljen u blizini graničnih ploha prostorije bez dodatnog apsorpcijskog materijala na zidovima prostorije.

Ključne riječi: *razina zvučne snage, zvuk, buka, mehanička oprema, održavanje*

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