MODELLING OF NOISE THREAT ASSESSMENT IN SMALL INDUSTRIAL ROOMS

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Abstract: The research done in the area of analysis and assessment of noise threatened working place concentrate on identification of sources of sound. In order to perform the assessment of noise threat in the examined space, there is a need to gather additional information, among others about the construction features of the place, its equipment, etc. The process of selection of used ways and methods is highly determined by the acoustic parameters of the sources of sound, their characteristics and localizations. The information related to geometric models of the places as well as material features of the barriers create a set of complimentary parameters – necessary for proper selection of noise reducing methods. Due to variety of application of methods of modeling the acoustic fields it was stated, that each of them has limited applicability in the research because of the shape of the place and characteristics of the field. Its main simplification is related to the assumption of stability of acoustic parameters of the field in the domain of time simultaneously excluding the wave phenomena. This article is an attempt to identify the sources of sound as the emitters of acoustic energy in the working place. In this approach, the sources are treated as either points emitting acoustic energy.

Keywords: noise threat, model, source sound, assessment of noise

1 Introduction

The analysis of acoustic energy in small rooms is of the greatest importance because of existence of wave phenomena such as: radiation, absorption, refraction and dispersion of an acoustic wave. Taking into account the wave phenomena in assessment of noise threat in the working environment enables to identify the meaning of their emergence in the energy-related description of an acoustic field. Energy-related approach to acoustic field allows to perform a more detailed analysis of ways of transmission and dispersion of acoustic energy directly from the source in the examined environment. In particular, thanks to such a description of the field, it is possible to analyze the variability of the shape of the waves and streams of energy in the frequency domain. Application of advanced graphical methods and assessment of distribution of acoustic energy in relation with the measurement methods allows to shape the noise threatened working place according to the requirements of ergonomics [2, 3].

2 Evaluating noise threat using geometric methods

The proposed model using geometric methods of noise simulation applies in particular to stationary noise sources and ergodic stationary signals (the mean value and the autocorrelation function are independent of time). The sound intensity parameter for any number of sound beam reflections can be expressed by means of the following generalized formula (1).

$$I_{ki} = \frac{N_i}{\Omega_i \cdot R_{ki}{}^2} \Pi(1 - \alpha_k)^N_{k=1} \qquad (1)$$

where:

N_i - *acoustic power of the j-th sound source,*

R_{ki} *-the distance of the sound beam from the i-th source to the k-th point,*

Ω_i $_{i-}$ *solid angle of the radiation of the i-th sound source,*

α_k *-sound absorption coefficients for the model surfaces.*

Isolating the attributes of acoustic parameters from (1), an a_{ik} coefficient is introduced, which describes the following relationship:

$$a_{ik} = \frac{(1 - \alpha_k)}{\Omega_i \cdot R_{ki}{}^2} \qquad (1.2)$$

After converting the (1.2) equation to a matrix form we receive the following:

$$|I| = |N| \cdot |A| \qquad (1.3)$$

where:

I – sound intensity vector

N- vector of acoustic sound sources,

A – coefficients matrix

With the matrix representation of equation (1.3) - it takes the following detailed form:

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ ... \\ I_n \end{vmatrix} = |N_1 N_2 N_3 ... N_n| \cdot \begin{vmatrix} a_{11} a_{12} a_{13} ... a_{1m} \\ a_{21} a_{22} a_{23} ... a_{2m} \\ a_{31} a_{32} a_{33} ... a_{3m} \\ ... \\ a_{n1} a_{n2} a_{n3} ... a_{nm} \end{vmatrix} \qquad (2)$$

The (theoretical) component values of sound intensity coming from the individual sound sources can be obtained through a sound simulation post-process, using N = 1[W] as acoustic power values for the sources. In this case the sound intensity vector includes the theoretical values of acoustic parameters at reception points. In order to determine the real acoustic power values of the sound sources for the calculated sound intensity values at reception points, the operation of reversing the coefficients matrix [A] must be performed. This matrix contains a description of the geometric and acoustic parameters of the system discussed here. The essence of the proposed model consists in determining the inverse matrix [A], which includes the spatial relationships of geometric position in

the source-receiver relationship as well as the geometry of the room, and takes into consideration the properties of the model's surface material [1].

$$\left|N\right| = \left|N_1 N_2 N_3 ... N_n\right| = \left|A\right|^{-1} \begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ ... \\ I_n \end{vmatrix} \tag{2.1}$$

The real values of acoustic power of sound sources on the basis of the values obtained for the intensity vector at reception points is determined using equation (2.1). For potential acoustic situations with 3 sound sources the noise exposure model using geometric methods of sound simulation takes the following form for the determined real values of acoustic power:

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \end{vmatrix} = \left|N_1 N_2 N_3\right| \cdot \begin{vmatrix} a_{11} a_{12} a_{13} \\ a_{21} a_{22} a_{23} \\ a_{31} a_{32} a_{33} \end{vmatrix} \tag{3}$$

The obtained set of relationships of acoustic situations caused by the sources (3) for the simulated acoustic field in a room is described by an approximated noise exposure risk matrix model.

2.1 The analysis of the results of sound simulation in a model room

A theoretical model room was prepared for the purpose of a computer simulation with the following dimensions: 3.2[m]x2.2[m]x2.7[m]. The model room was designed as an ideal echo-free chamber with 3 spherical sources and 14 reception points situated at the height of 1 [m]; the $\alpha = 1$ coefficient was used for all the walls. It was decided that sources S_1 and S_2 will be situated at the height of 0.5 [m] and source S_3 at the height of 1 [m]. The simulation parameters for the calculations were 5000 beams of sound from each source and 2000 reflections. According to equation (2) presented below equal acoustic power levels L_N of 120 dB (A) were used for all the sources.

$$L_N = \left|120 \quad 120 \quad 120\right|\left[dB(A)\right]$$

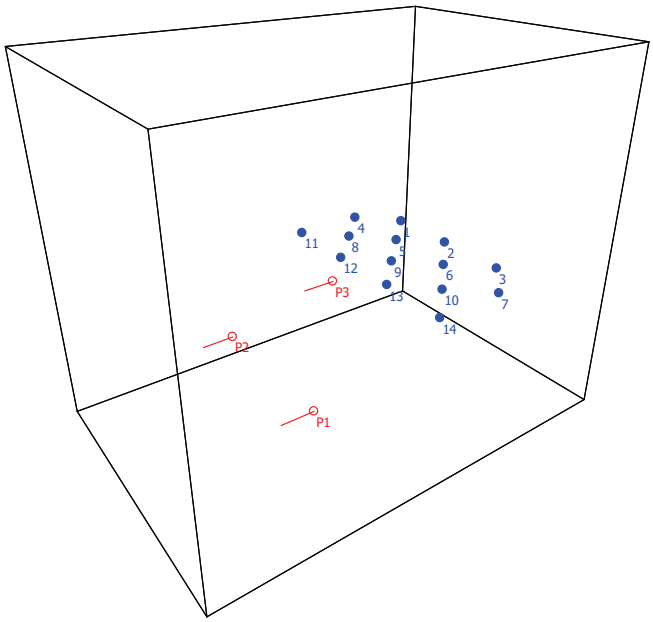

Fig. 1. Simulation model of the room

Following the sound simulation the sound levels coming from the respective sources S_1, S_2, S_3. were obtained for 3 selected reception points (1,2,3). The following values were obtained from source S_1 at 3 reception points:

$$S_1 = \begin{bmatrix} 101{,}5 \\ 102{,}6 \\ 103 \end{bmatrix} [dB(A)]$$

The following values were obtained from source *S2* at 3 reception points:

$$S_2 = \begin{bmatrix} 103 \\ 102{,}6 \\ 101{,}5 \end{bmatrix} [dB(A)]$$

The following values were obtained from source *S3* at 3 reception points:

$$S_3 = \begin{bmatrix} 106 \\ 107 \\ 106 \end{bmatrix} [dB(A)]$$

Using the above and converting the units in matrix [A], the matrix was then inverted:

$$|A|^{-1} = \begin{vmatrix} 10{,}922 & 182{,}530 & -70{,}238 \\ -153{,}665 & -153{,}655 & 131{,}537 \\ 182{,}530 & 10{,}922 & -70{,}238 \end{vmatrix} \left[1/m^2 \right]$$

After converting the units appropriately and substituting them in equation (3) and after multiplication total values of intensity vector in the individual points coming from sources S_1, S_2, S_3 are obtained.

$$|I| = \begin{vmatrix} 0{,}073 \\ 0{,}086 \\ 0{,}073 \end{vmatrix} \left[W/m^2 \right]$$

The model can be verified by determining the value of acoustic power levels of the sources on the basis of the obtained results of the sound level at the same reception points in the model. The sound simulation yielded the following values of sound level at 3 reception points – successively from sources S_1, S_2, S_3:

$$S_1 = \begin{bmatrix} 63{,}5 \\ 64{,}6 \\ 65 \end{bmatrix} [dB(A)],\ S_2 = \begin{bmatrix} 65 \\ 64{,}6 \\ 63{,}5 \end{bmatrix} [dB(A)],\ S_3 = \begin{bmatrix} 63 \\ 64 \\ 63 \end{bmatrix} [dB(A)]$$

The total values of the intensity vector in the examined points are:

$$|I| = \begin{vmatrix} 0{,}000158 \\ 0{,}0000158 \\ 0{,}0000501 \end{vmatrix} \left[W/m^2 \right]$$

After substituting them in equation (2.1), multiplying the matrix and converting the units, acoustic power values of sources S_1, S_2, S_3 are obtained.

$$L_N = |80 \quad 80 \quad 75| [dB(A)]$$

The verification of the proposed matrix model confirmed that the levels of acoustic power of the sources used for the simulation were correct.

After substituting them in equation (2.1) the values of acoustic power L_N for the 3 reception points were calculated taking into account various acoustic situations of the source activity.

Table 1. Combinations of acoustic situations, sound sources and sound levels

Acoustic situations	L_{N1} *[dB(A)]*	L_{N2} *[dB(A)]*	L_{N3} *[dB(A)]*
S_1	80	0	0
S_2	0	80	0
S_3	0	0	75
S_1,S_2	79,89	79,89	62
S_2,S_3	67,74	79,97	74,67
S_1,S_3	79,97	67,74	74,67
S_1,S_2,S_3	80,67	80,67	72,44

The values of acoustic power obtained for the reception points in question for the alternatives of two and three active sources (table 1) are similar to the values of the respective sources. However, in these acoustic situations there are sound level values from sources, which should yield zero values. An analysis of the results of the acoustic parameters simulation for the selected alternative of the operation of sources S_1, S_2, S_3 was carried out using the *Odeon 8.5* software.

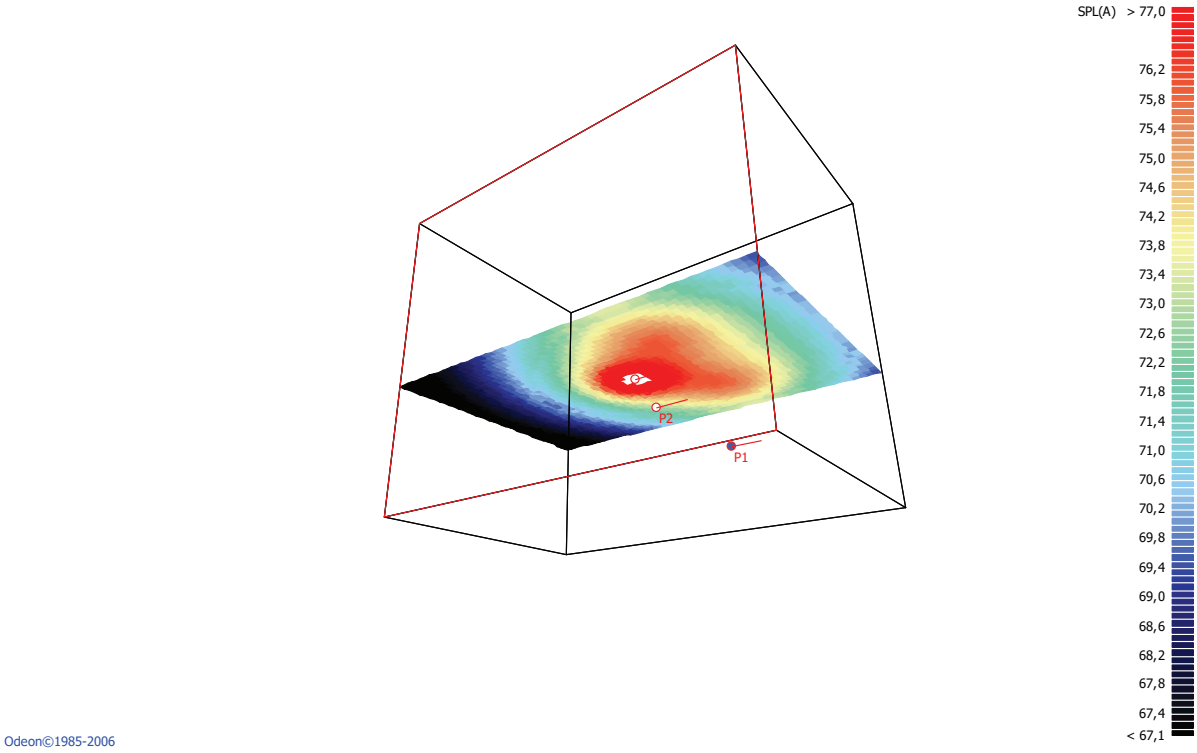

Fig. 2. Sound level distribution map at the height of source S_3 in the model room

In the simulation the sound level values were different at the reception points due to their position in space (Fig. 3).

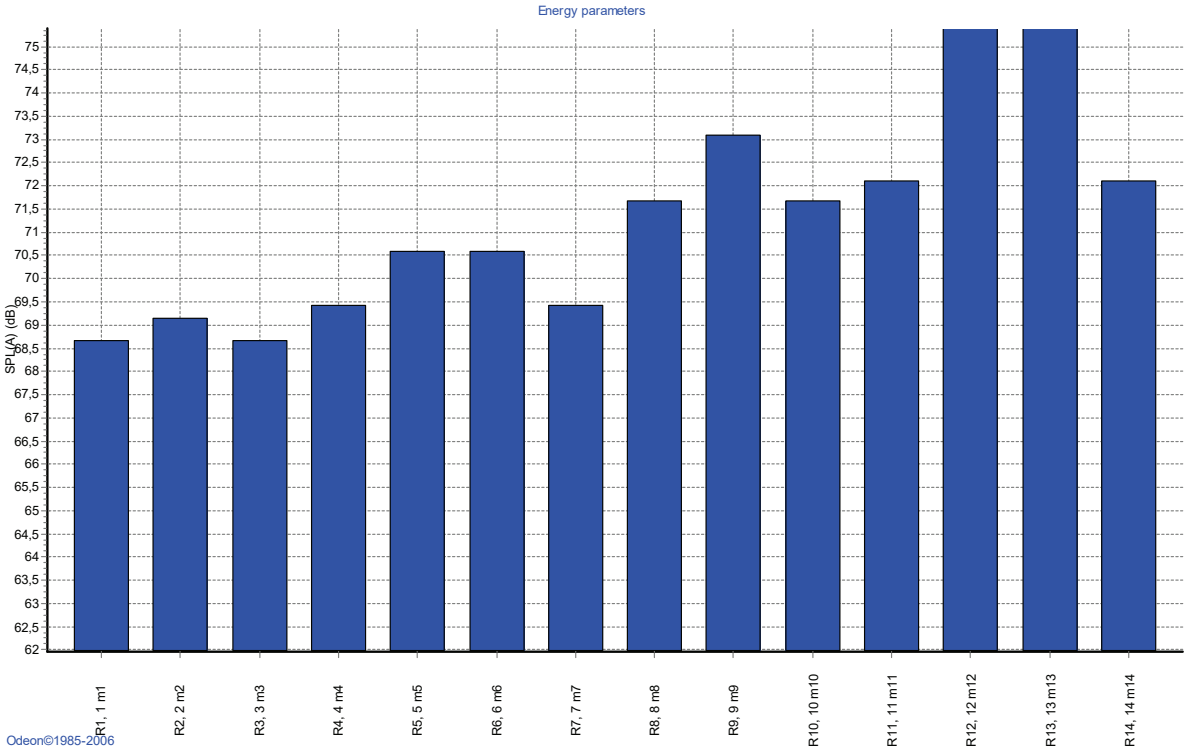

Fig. 3. Sound level distribution at reception points

The sound level value distribution at reception points in octave frequencies does not show variability (Fig. 4). The simulation results show that the largest energetic share of the sources in 1 reception point occurs at the 2000 [Hz] frequency. The results obtained from the simulation (table 1) at the reception points for the proposed noise threat evaluation model show some discrepancies. This is caused by the dimensions of the room and the limitations of the geometric simulation methods used. The distribution of acoustic energy from the sound sources in limited spaces mainly depends on the shape and the ratio between the room dimensions and the length of the emitted waves. In the case in question the room dimensions are relatively small in relation to the wavelengths. Additionally, in small rooms wave phenomena occur which are not accounted for in the geometric simulation methods.

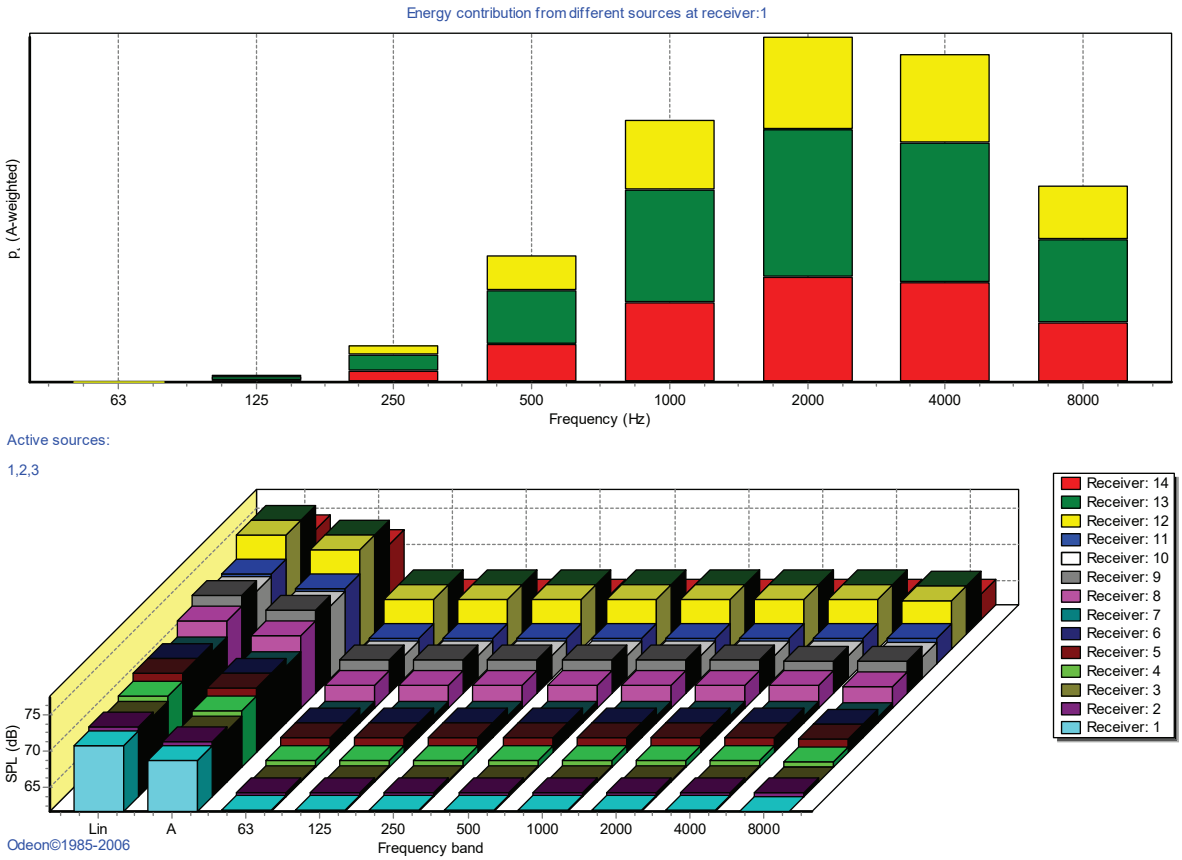

Fig. 4. The share of source energy in point 1 and sound level distribution at reception points for octave frequency bands

Conclusion

1. The proposed noise exposure matrix model can be used to evaluate the level of acoustic powers of the sources on the basis of the acoustic parameter values at the reception points. Another important element of the model is the coefficient matrix [A] of the analyzed room, which refers to the adopted relations: source-receiver and their invariable geometric and acoustic properties. This model was used in the formula to describe geometric methods of sound simulation, which are not sufficient in the case of the analyzed room due to the limited applicability of the method. The results obtained in the model analysis indicate certain discrepancies when acoustic alternatives of several active sources were analyzed.

2. It is proposed that MES/MEB numerical methods should be used in sound simulation when studying the interference of the sources in small rooms. The analysis of the interference of the sources in terms of frequency and effects will make it possible to evaluate a precise impact this phenomenon has on noise threat. For this purpose, it is planned that such analyses should first be performed on the analyzed model of the room (Fig.1) and comparing the results obtained by geometric methods with FEM/BEM.
3. Further research will be connected with creating simulation models of rooms representing real-life systems for which the sound simulation analyses will be verified by means of measurement methods. When the measurement values verify the simulation results a way can be elaborated to evaluate the impact of interference of the sources on noise threat.

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MODELOWANIE OCENY ZAGROŻENIA HAŁASEM W MAŁYCH POMIESZCZENIACH PRZEMYSŁOWYCH

Streszczenie: Badania przeprowadzone w zakresie analizy i oceny hałasu zagrażającego miejscom pracy koncentrują się na identyfikacji źródeł dźwięku. W celu przeprowadzenia oceny zagrożenia hałasem w badanej przestrzeni, istnieje potrzeba zebrania dodatkowych informacji, m.in. o cechach konstrukcyjnych miejsca, jego wyposażeniu, itp. Proces wyboru stosowanych sposobów i metod jest zdeterminowany przez parametry akustyczne źródeł dźwięku, ich charakterystyki i lokalizacje. Informacje niezbędne do modelowania, reprezentowane przez miejsca położenia pracownika i źródeł oraz cechy materiałowe barier akustycznych tworzą zestaw parametrów niezbędnych do doboru metod redukcji poziomu hałasu. Ze względu na różne zastosowania metod modelowania pól akustycznych stwierdzono, że każda z nich ma ograniczone zastosowanie w badaniach ze względu

na ukształtowanie pomieszczenia i cechy pola akustycznego. Głównym uproszczeniem jest założenie stabilności parametrów akustycznych polu akustycznego w czasie oraz pominięcie zjawisk falowych. Niniejszy artykuł opisuje sposób identyfikacji źródeł dźwięku jak emiterów energii akustycznej w miejscach pracy. W proponowanym podejściu źródła są traktowane jako punkty emitujące energię akustyczną.

Słowa kluczowe: zagrożenie hałasem, model, źródło dźwięku, ocena hałasu.