9

IDENTIFICATION AND MODELING OF EMISSION SOUND SOURCES AT WORK STATIONS

9.1 INTRODUCTION

The research done in the area of analysis and assessment of noise threatened working place concentrate in the first chase 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 or areas emitting acoustic energy. The analysis of flow of acoustic energy may be treated as examination of propagation of waves from the sources of sound. Taking into account the energy-related results caused by the flow of acoustic wave creates the new possibilities in the research on identification of sound sources in small rooms. The analysis of flow 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 visualization of flows of acoustic energy in relation with the measurement methods allows to shape the noise threatened working place according to the requirements of ergonomics.

9.2 EVALUATING NOISE THREAT USING GEOMETRIC METHODS

9.2.1 Noise exposure model

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:

$$I_{ki} = \frac{N_i}{\Omega_i \cdot R_{ki}^{\,2}} \prod_{k=1}^{N} (1-\alpha_k) \tag{9.1}$$

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 (9.1), an a_{ik} coefficient is introduced, which describes the following relationship:

$$a_{ik} = \frac{(1-\alpha_k)}{\Omega_i \cdot R_{ki}^{\,2}} \tag{9.2}$$

After converting the (9.2) equation to a matrix form we receive the following:

$$|I| = |N| \cdot |A| \tag{9.3}$$

where:

I – sound intensity vector

N – vector of acoustic sound sources,

A – coefficients matrix

With the matrix representation of equation (9.3) – it takes the following detailed form:

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ \ldots \\ I_n \end{vmatrix} = \left| N_1 N_2 N_3 \ldots N_n \right| \cdot \begin{vmatrix} a_{11}a_{12}a_{13}\ldots a_{1m} \\ a_{21}a_{22}a_{23}\ldots a_{2m} \\ a_{31}a_{32}a_{33}\ldots a_{3m} \\ \ldots \\ a_{n1}a_{n2}a_{n3}\ldots a_{nm} \end{vmatrix} \tag{9.4}$$

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.

$$|N| = |N_1 N_2 N_3 \ldots N_n| = |A|^{-1} \begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ \ldots \\ I_n \end{vmatrix} \tag{9.5}$$

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 (9.5).

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:

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \end{vmatrix} = |N_1 N_2 N_3| \cdot \begin{vmatrix} a_{11} a_{12} a_{13} \\ a_{21} a_{22} a_{23} \\ a_{31} a_{32} a_{33} \end{vmatrix} \tag{9.6}$$

The obtained set of relationships of acoustic situations caused by the sources (9.3) for the simulated acoustic field in a room is described by an approximated noise exposure risk matrix model.

9.2.2 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] (fig. 9.1). 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 P_1 and P_2 will be situated at the height of 0.5 [m] and source P_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 (4) presented below equal acoustic power levels L_N of 120 dB (A) were used for all the sources.

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

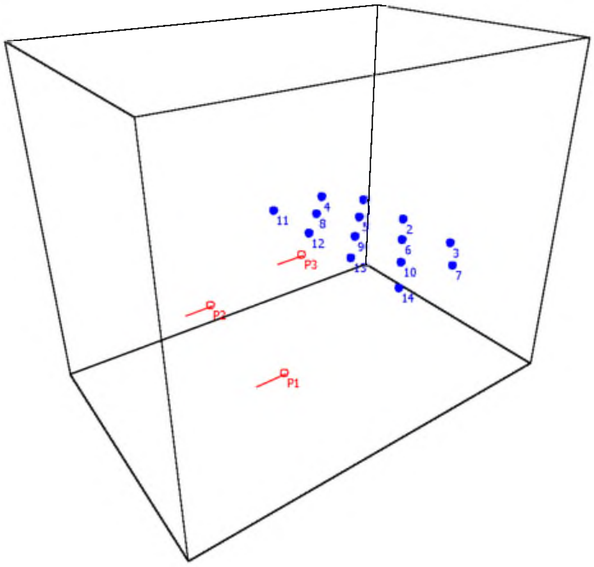
Following the sound simulation the sound levels coming from the respective sources P_1, P_2, P_3. were obtained for 3 selected reception points (1, 2, 3).

The following values were obtained from source P_1 at 3 reception points:

$$P_1 = \begin{bmatrix} 101{,}5 \\ 102{,}6 \\ 103 \end{bmatrix} [dB(A)]$$

The following values were obtained from source P_2 at 3 reception points:

$$P_2 = \begin{bmatrix} 103 \\ 102{,}6 \\ 101{,}5 \end{bmatrix} [dB(A)]$$



Odeon©1985-2006

Fig. 9.1 Simulation model of the room

The following values were obtained from source P_3 at 3 reception points:

$$P_3 = \begin{bmatrix} 106 \\ 107 \\ 106 \end{bmatrix} [dB(A)]$$

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

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

After converting the units appropriately and substituting them in equation (9.6) and after multiplication total values of intensity vector in the individual points coming from sources P_1, P_2, P_3 are obtained.

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

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 P_1, P_2, P_3:

$$P_1 = \begin{bmatrix} 63{,}5 \\ 64{,}6 \\ 65 \end{bmatrix} [dB(A)], \ P_2 = \begin{bmatrix} 65 \\ 64{,}6 \\ 63{,}5 \end{bmatrix} [dB(A)], \ P_3 = \begin{bmatrix} 63 \\ 64 \\ 63 \end{bmatrix} [dB(A)]$$

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 (9.5), multiplying the matrix and converting the units, acoustic power values of sources P_1, P_2, P_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 (9.5) 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 9.1 Sound power level values in pending television receiving equipment points

Acoustic situations	L_{N1} [dB(A)]	L_{N2} [dB(A)]	L_{N3} [dB(A)]
P_1	80	0	0
P_2	0	80	0
P_3	0	0	75
P_1, P_2	79.89	79.89	62
P_2, P_3	67.74	79.97	74.67
P_1, P_3	79.97	67.74	74.67
P_1, P_2, P_3	80.67	80.67	72.44

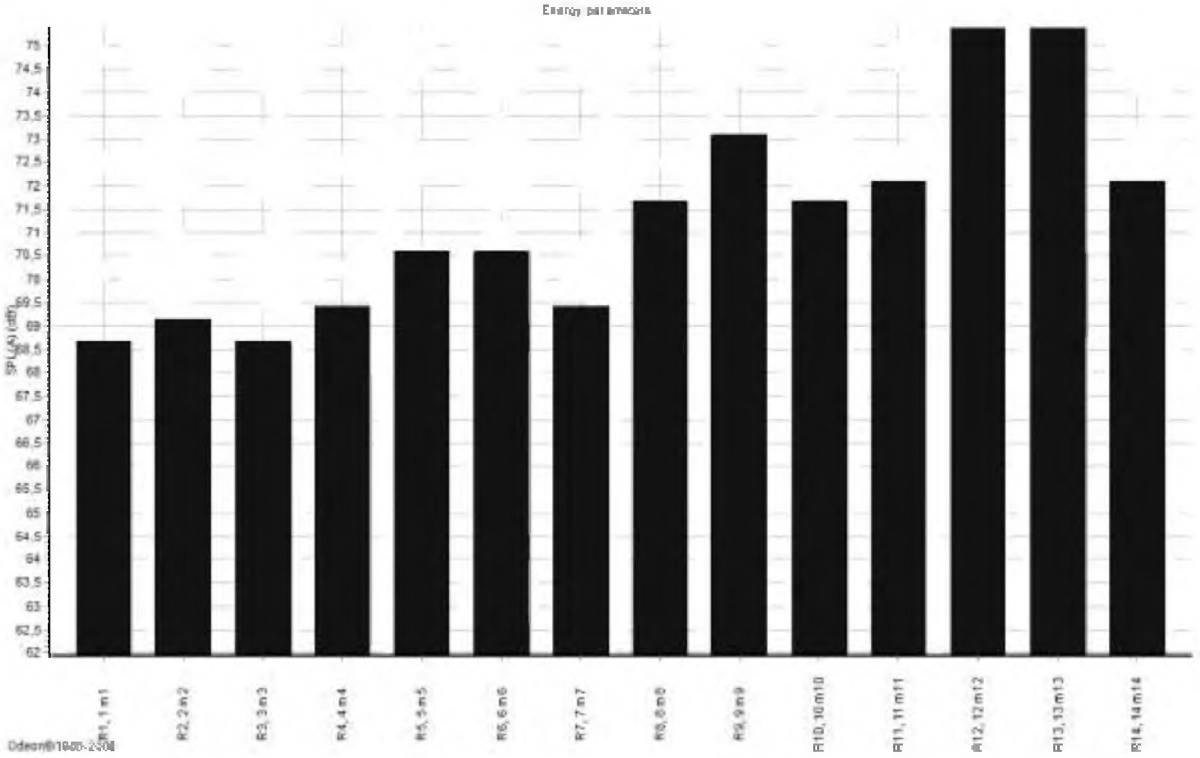


Fig. 9.2 Sound level distribution map at the height of source P_3 in the model room

In the simulation the sound level values were different at the reception points due to theirposition in space (Figure 9.3)

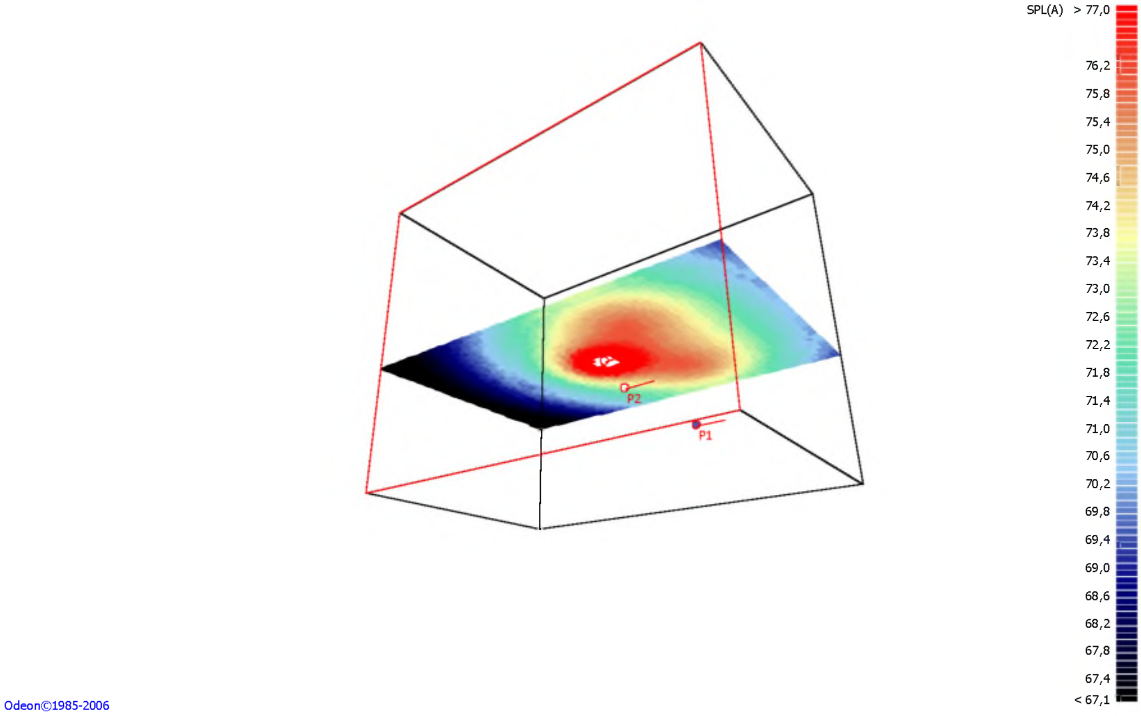


Fig. 9.3 Sound level distribution at reception points

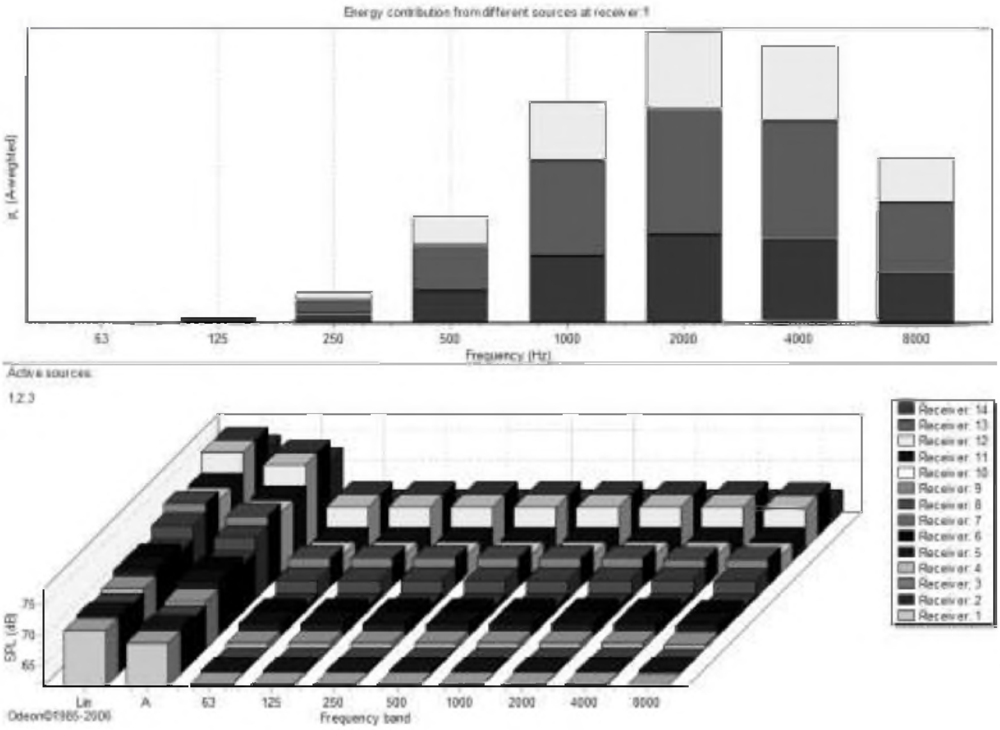


Fig. 9.4 The share of source energy in point 1 and sound level distribution at reception points for octave frequency bands

The values of acoustic power obtained for the reception points in question for the alternatives of two and three active sources (table 9.1) 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 P_1, P_2, P_3 was carried out using the *Odeon 8.5* software.

The sound level value distribution at reception points in octave frequencies does not show variability (fig. 9.2). The simulation results show that the largest energetic share of the sources in 1 reception point occurs at the 2000 [Hz] frequency.

9.3 THE ANALYSIS OF THE PHENOMENA OF INTERFERENCE OF SOUND SOURCES FOR THE PURPOSE OF NOISE THREAT EVALUATION

The results obtained from the simulation (table 9.1) 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. The aspects described above may result in discrepancies in the results of the analysis of the acoustic situations of the sound sources.

9.3.1 The analysis of the interference of the sources using a sound intensity vector

The problem to be subjected to further research consists in preparing a noise threat evaluation model which will account for the phenomenon of the interference of sound sources. It will be important to determine the impact of the occurrence of interference of the sources on the results of noise threat evaluation in small rooms.

The research which has already been completed in this area [1, 2], which uses intensity methods, proves to be more effective in terms of the results of the analysis of acoustic phenomena in small rooms compared to the methods based on the distribution of acoustic pressures.

The sound intensity vector represented by the methods listed above includes component values of intensity in three perpendicular directions. This makes it possible to perform an analysis of the interactions of the sources and to analyze their energetic wave effects (e.g. an analysis of phase relations between sound source signals).

The theoretical models used in the techniques of acoustic field distribution in small rooms contain certain limitations. They mainly consist in that a set of acoustic phenomena often occurs in the analyzed system, such as: interference of reflected and scattered waves, absorption, diffraction, the formation of standing waves. Each of the phenomena listed above is known in its theory and described as a discrete phenomenon. The problem which describes the synthesis of acoustic phenomena in small rooms is complex enough for a representation of such theoretical model not yet to be known.

9.3.2 Using sound simulation methods in noise threat evaluation

The significance of the interference of sound sources for the evaluation of noise threat can be analyzed using computerized ‘idealized’ room models. Such models should: describe the parameters of the sources and the receivers, the walls of all the surfaces should be ideally absorptive and should not contain any partitions. Performing a sound simulation in such a model will help analyze interference.

An energetic approach is proposed for carrying out analyses of interference. In this approach energetic interactions of an acoustic wave taking place between the sources will be analyzed. Research on the propagation of acoustic energies in rooms, taking into account wave phenomena and using numerical methods are described in detail in [3].

It is suggested that further research should consist in carrying out a sound simulation on a model (fig. 1) using tools to analyze wave phenomena. For this purpose it is proposed that FEM/BEM methods be used for the needs of numerical modeling of acoustic radiation issues and the description of the reactions of the structures triggered by the energy of the traveling acoustic wave. The research should focus on the vector distribution of acoustic field, accounting for the interferential effects of the active sources in relation to phase relations and frequency bands.

CONCLUSIONS

- 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.
- It is proposed that FEM/BEM 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.
- 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.

REFERENCES

1. Zmysłowski A., Kuboszek A.: Estymacja źródeł dźwięku i symulacja dyfuzyjnego pola akustycznego. *Materiały XXVII Szkoły Zimowej Zwalczania Zagrożeń Wibroakustycznych* Gliwice-Ustroń, 1999.pp 261-266.
2. Atelier scientifiques franco-polonais sur le: "Uwarunkowania przydatności systemów informatycznych wspomagających zarządzanie w przedsiębiorstwie produkcyjnym i handlowym w warunkach transformacji gospodarczej" ENSM.SE, France 2000.
3. Weyna S.: *Rozpływ energii akustycznych źródeł rzeczywistych*. WNT, Warszawa, 2005.

IDENTIFICATION AND MODELING OF EMISSION SOUND SOURCES AT WORK STATIONS

Abstract: *The research done in the area of analysis and assessment of noise threatened working place concentrate in the first chase 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 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.*

The analysis of flow 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.

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 or areas emitting acoustic energy. The analysis of flow of acoustic energy may be treated as examination of propagation of waves from the sources of sound. Taking into account the energy-related results caused by the flow of acoustic wave creates the new possibilities in the research on identification of sound sources in small rooms.

Key words: *acoustic energy, flows of acoustic energy, noise threat*

IDENTYFIKACJI I MODELOWANIE EMISJI ŹRÓDEŁ DŹWIĘKU NA STANOWISKACH PRACY

Streszczenie: *Badania przeprowadzone w zakresie analizy i oceny hałasu zagrażającego miejscom pracy koncentrują się w pierwszym rzędzie na identyfikacji źródeł dźwięku. W celu przeprowadzenia oceny zagrożenia hałasem w badanej przestrzeni, istnieje potrzeba zebrania dodatkowych informacji, m.in. o cechach konstrukcyjnych pomieszczenia, jego wyposażenia, itp. Informacje niezbędne do modelowania, reprezentowane przez miejsca położenia oraz cechy materiałowe barier akustycznych tworzą zbiór parametrów, niezbędnych do prawidłowego doboru metod redukcji poziomu hałasu.*

Analiza przepływu energii akustycznej w małych pomieszczeniach ma duże znaczenie z powodu występowania zjawisk falowych, takich jak: promieniowanie, absorpcja, załamanie i rozproszenie fali akustycznej. Uwzględnienie występowania zjawisk falowych w ocenie zagrożenia hałasem w środowisku pracy pozwala zidentyfikować znaczenie ich występowania w energetycznym opisie pola akustycznego.

Niniejszy artykuł opisuje sposób zidentyfikowania źródeł dźwięku jak emiterów energii akustycznej w miejscu pracy. W tym podejściu, źródła traktowane są jako punkty, elementy liniowe, bądź powierzchniowe emitujące energię akustyczną. Analiza przepływu energii akustycznej traktowana może być jako badanie propagacji fal od źródeł dźwięku. Dotychczasowe wyniki badań nad przepływem energii związanym z propagacją fali akustycznej pozwalają określić nowe kierunki w badaniach nad identyfikacją cech źródeł dźwięku w małych pomieszczeniach.

Słowa kluczowe: *energia akustyczna, przepływy energii akustycznej, zagrożenie hałasem*

dr inż. Waldemar PASZKOWSKI, dr inż. Artur KUBOSZEK
Silesian University of Technology, Department of Organization and Management
Institute of Production Engineering
ul. Roosevelta 26, 41-800 Zabrze
e-mail: Waldemar.Paszkowski@polsl.pl; Artur.Kuboszek@polsl.pl